US010540530B2

(12) **United States Patent**
Yoscovich et al.

(10) **Patent No.: US 10,540,530 B2**
(45) **Date of Patent: Jan. 21, 2020**

(54) **METHODS FOR MAPPING POWER GENERATION INSTALLATIONS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **16/014,596**

(22) Filed: **Jun. 21, 2018**

(65) **Prior Publication Data**

US 2019/0095666 A1 Mar. 28, 2019

Related U.S. Application Data

(63) Continuation of application No. 15/447,981, filed on Mar. 2, 2017, now Pat. No. 10,061,957.

(60) Provisional application No. 62/381,298, filed on Aug. 30, 2016, provisional application No. 62/303,017, filed on Mar. 3, 2016.

(51) **Int. Cl.**

G06K 7/14	(2006.01)
H02S 50/00	(2014.01)
G06F 17/11	(2006.01)
G06K 7/10	(2006.01)

(52) **U.S. Cl.**

CPC ***G06K 7/1413*** (2013.01); ***G06F 17/11*** (2013.01); ***G06K 7/10366*** (2013.01); ***H02S 50/00*** (2013.01)

(58) **Field of Classification Search**

CPC .. G06K 7/1413; G06K 7/10366; G06F 17/11; H02S 50/00

See application file for complete search history.

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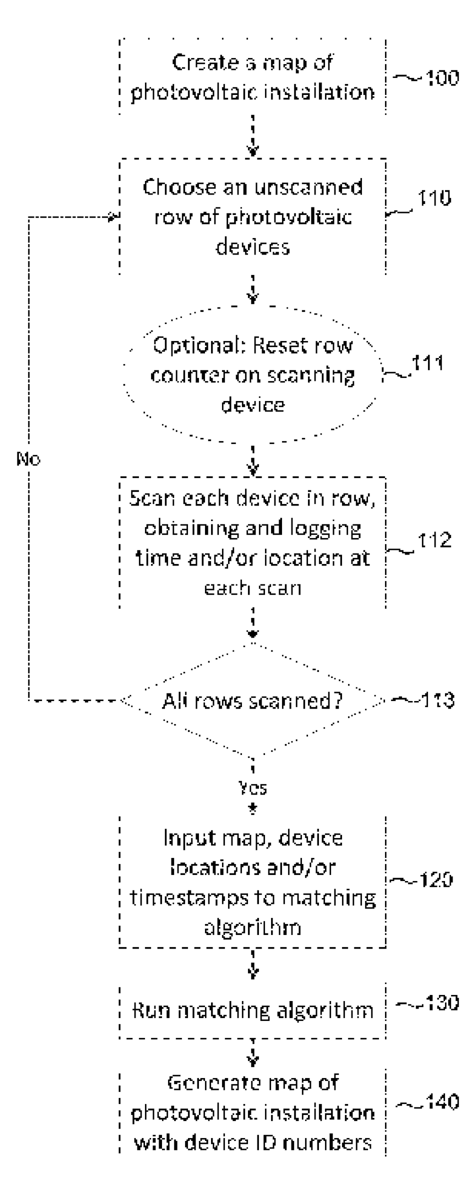
(57) **ABSTRACT**

Various implementations described herein are directed to a method for recording, by a device, identifying information of a plurality of components of a photovoltaic (PV) installation. The method may record, by the device, at least one of timestamps or locations corresponding to each component of the plurality of components. The method may generate, based on the identifying information, timestamps, and locations, a map of the PV installation.

20 Claims, 30 Drawing Sheets



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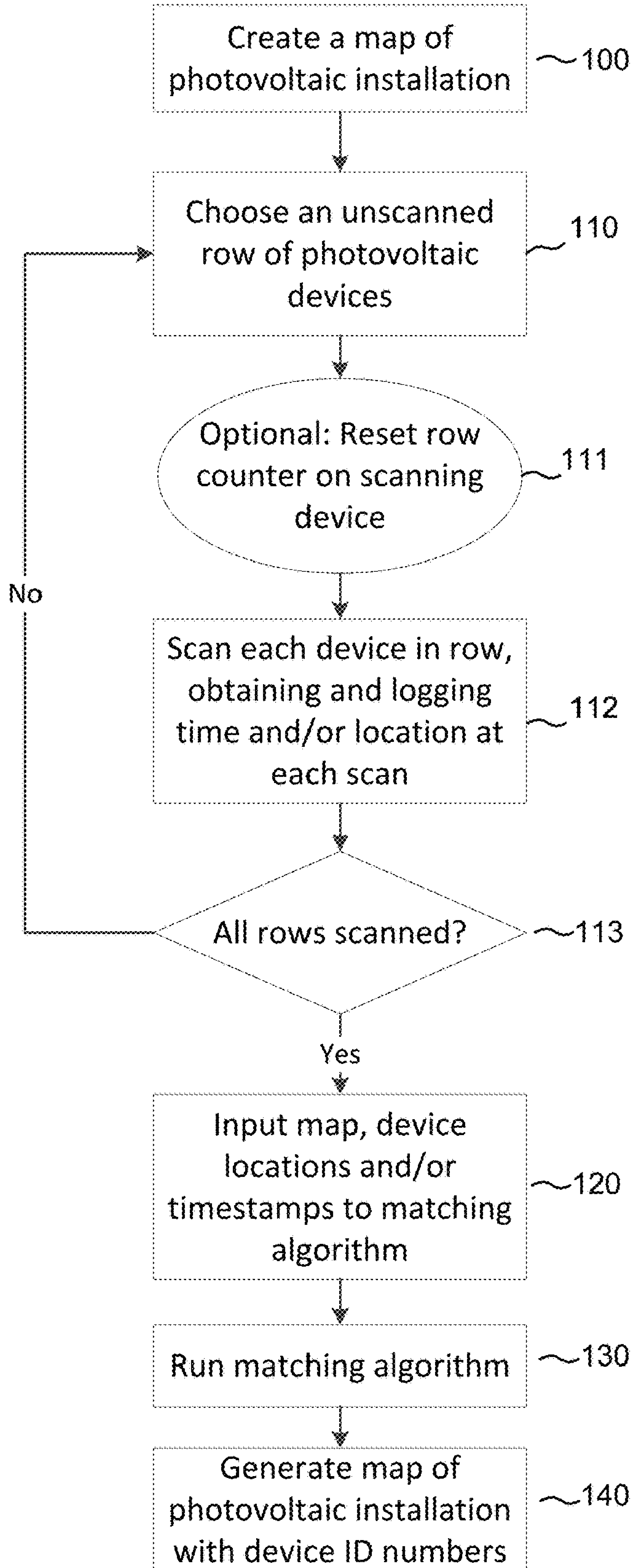

Create a map of photovoltaic installation
100
Choose an unscanned row of photovoltaic devices
110
Optional: Reset row counter on scanning device
111
No
Scan each device in row, obtaining and logging time and/or location at each scan
112
All rows scanned?
113
Yes
Input map, device locations and/or timestamps to matching algorithm
120
Run matching algorithm
130
Generate map of photovoltaic installation with device ID numbers
140

Fig. 1

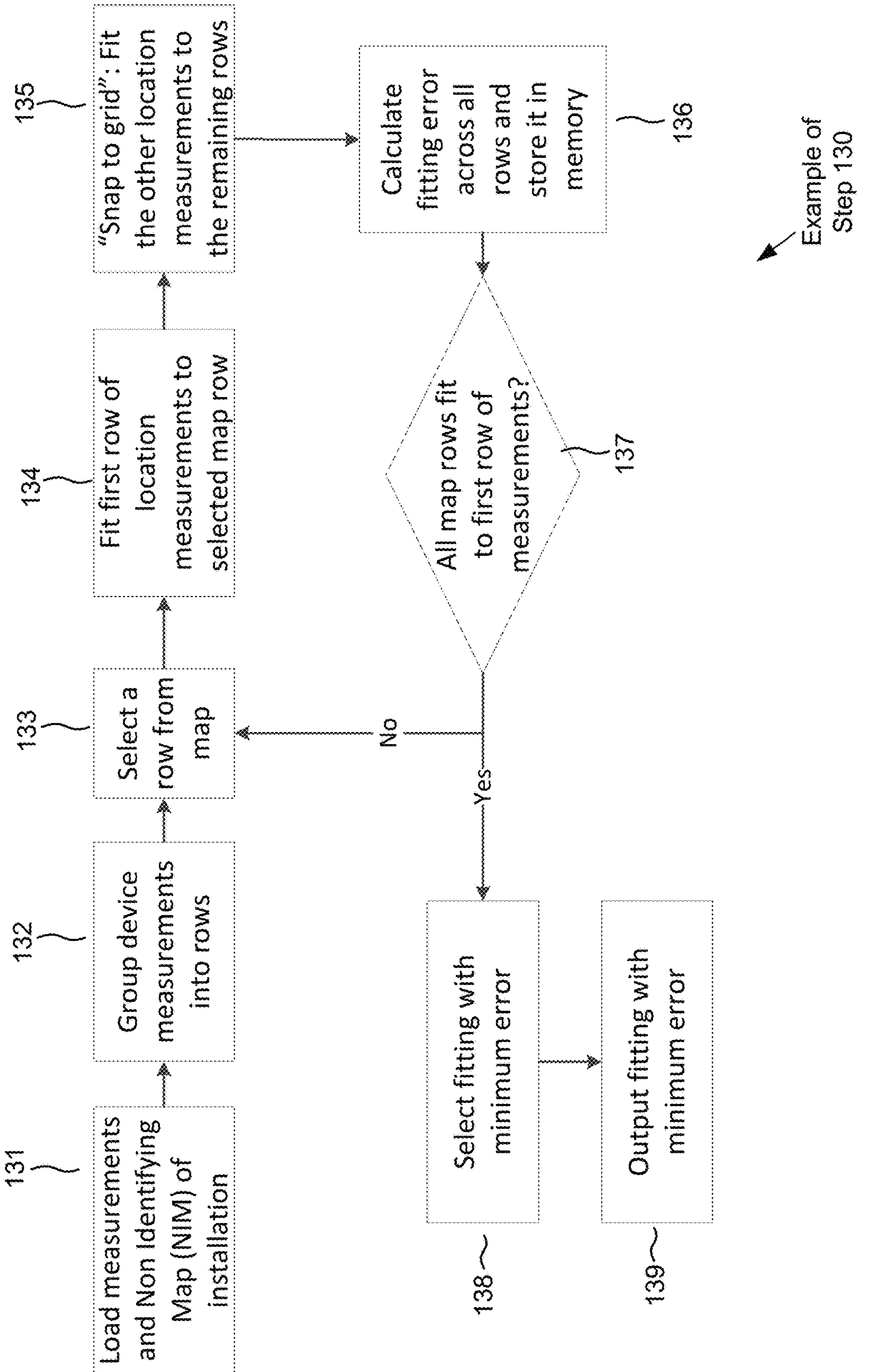

131
Load measurements and Non Identifying Map (NIM) of installation
132
Group device measurements into rows
133
Select a row from map
134
Fit first row of location measurements to selected map row
135
"Snap to grid": Fit the other location measurements to the remaining rows
136
Calculate fitting error across all rows and store it in memory
137
All map rows fit to first row of measurements?
No
Yes
138
Select fitting with minimum error
139
Output fitting with minimum error
Example of Step 130

Fig. 2A

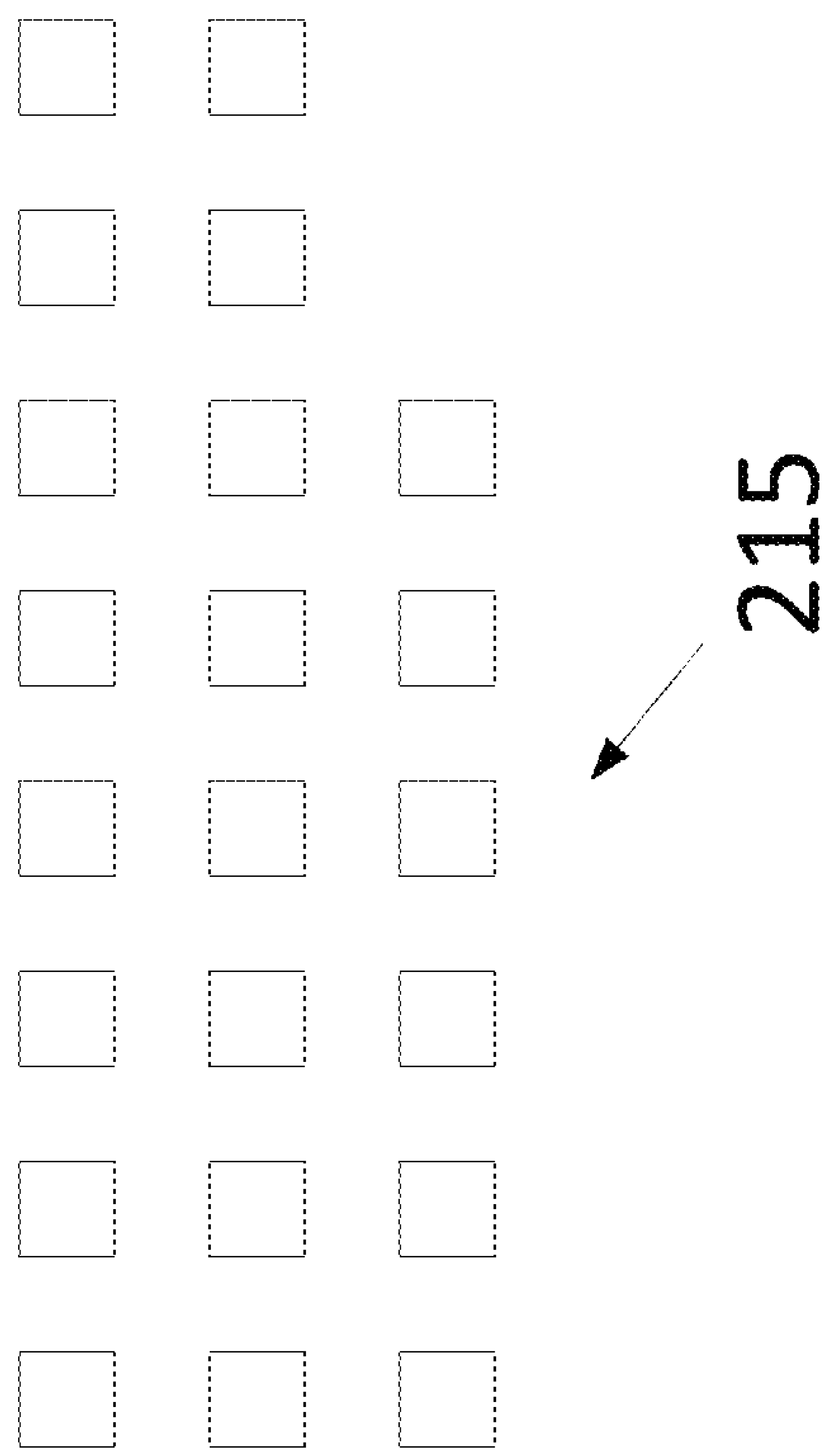


Fig. 2B

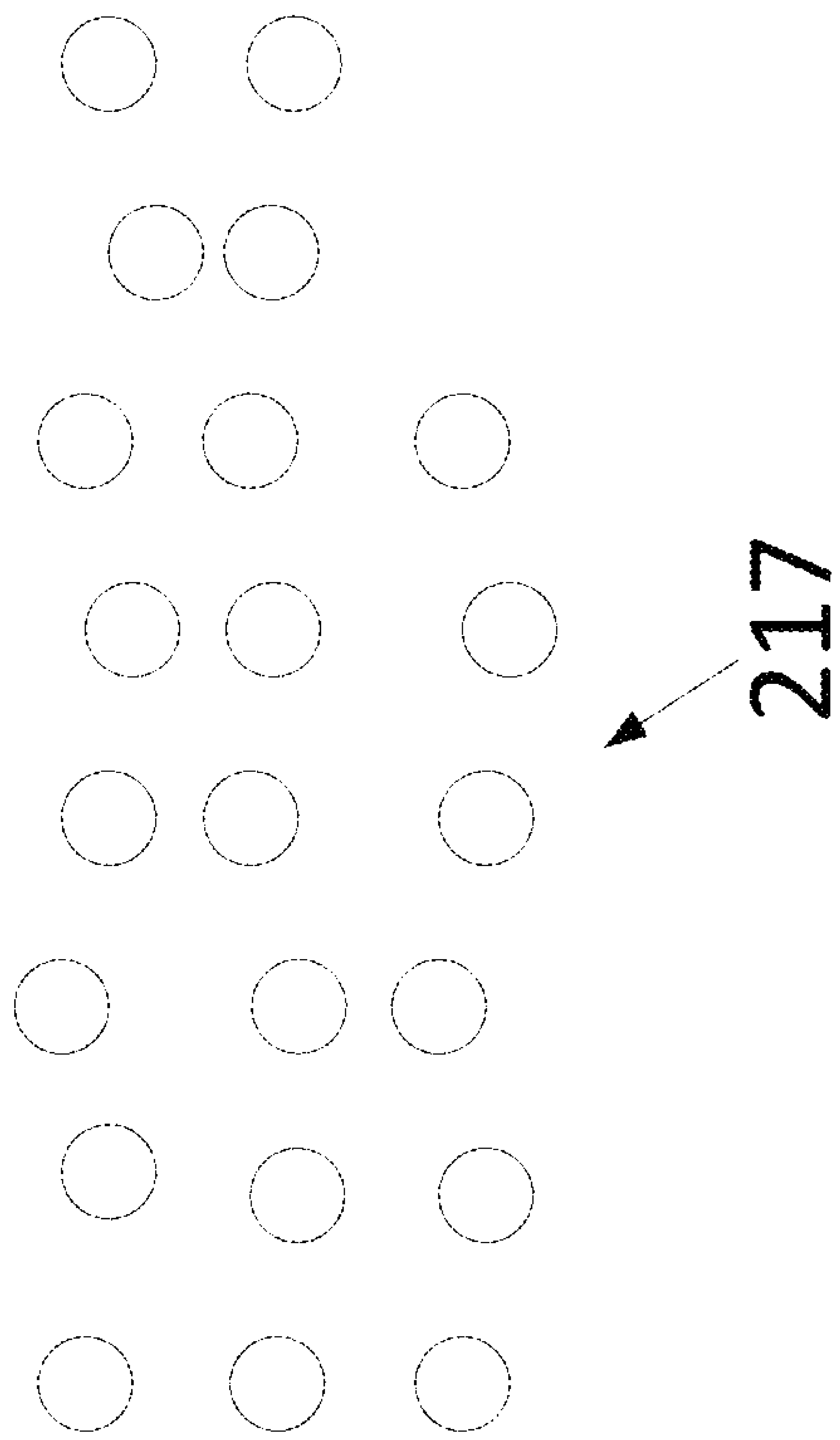


Fig. 2C

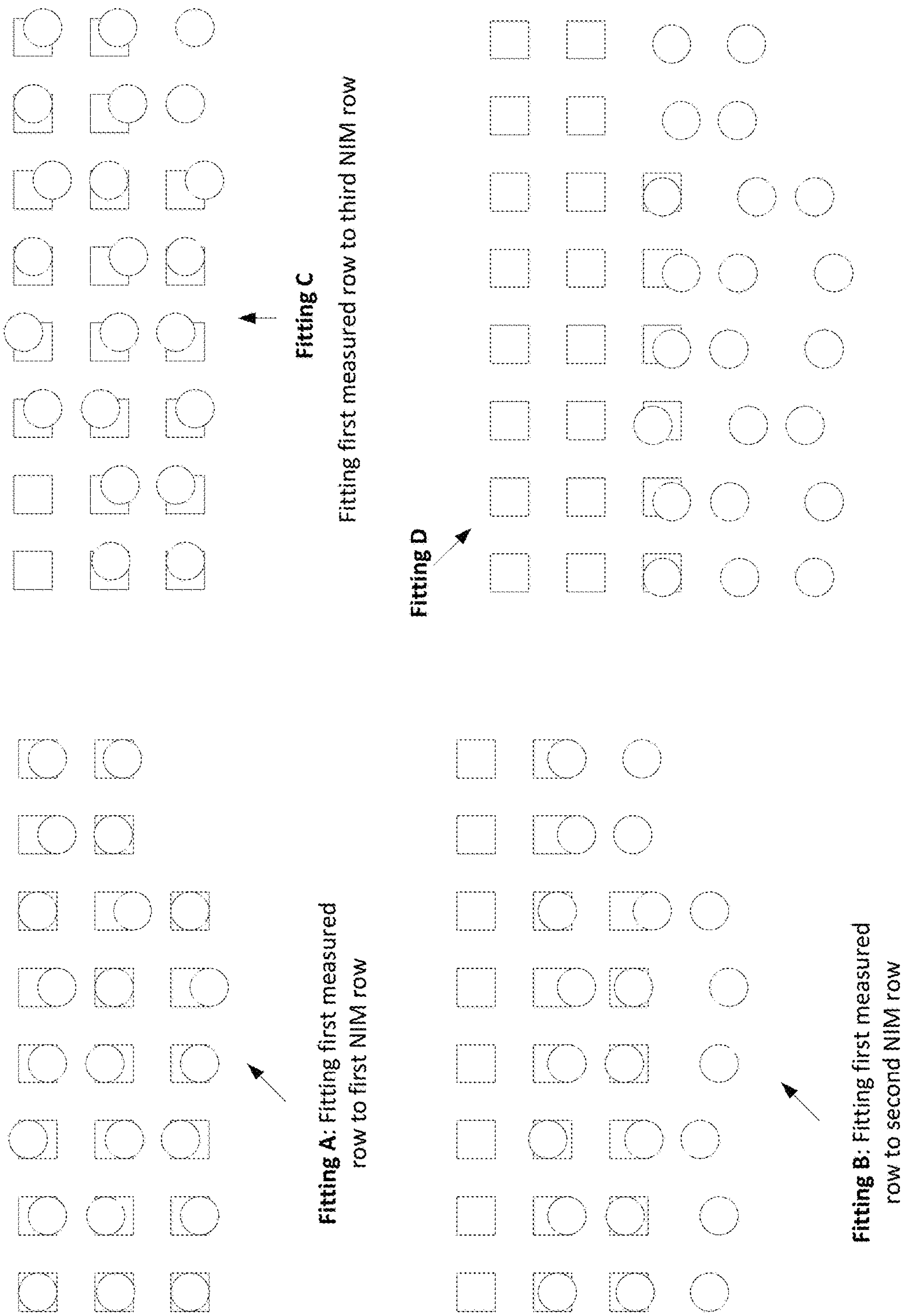

Fitting C
Fitting first measured row to third NIM row
Fitting D
Fitting A: Fitting first measured row to first NIM row
Fitting B: Fitting first measured row to second NIM row

Fig. 2D

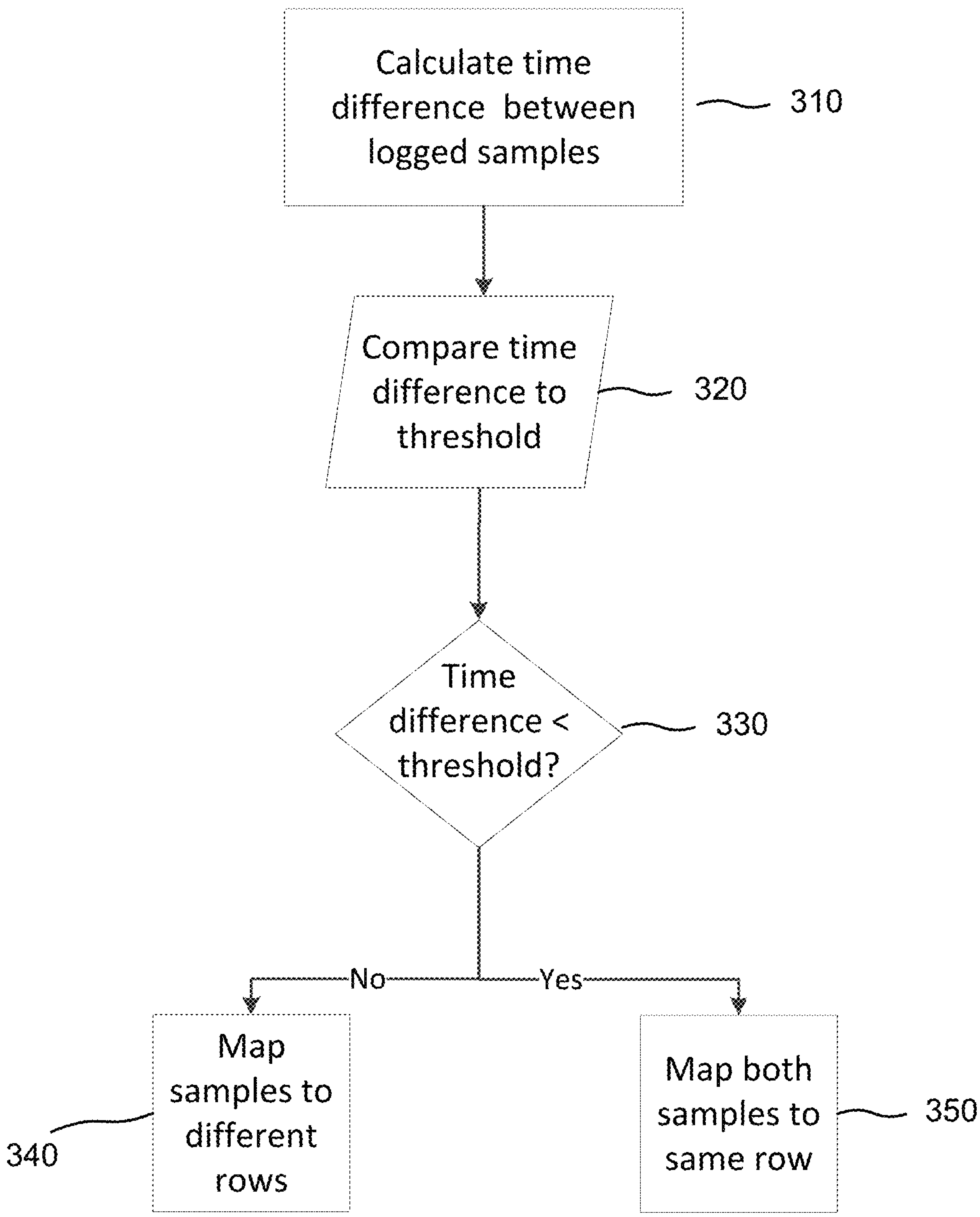

Calculate time difference between logged samples
310
Compare time difference to threshold
320
Time difference < threshold?
330
No
Yes
Map samples to different rows
340
Map both samples to same row
350

Fig. 3A

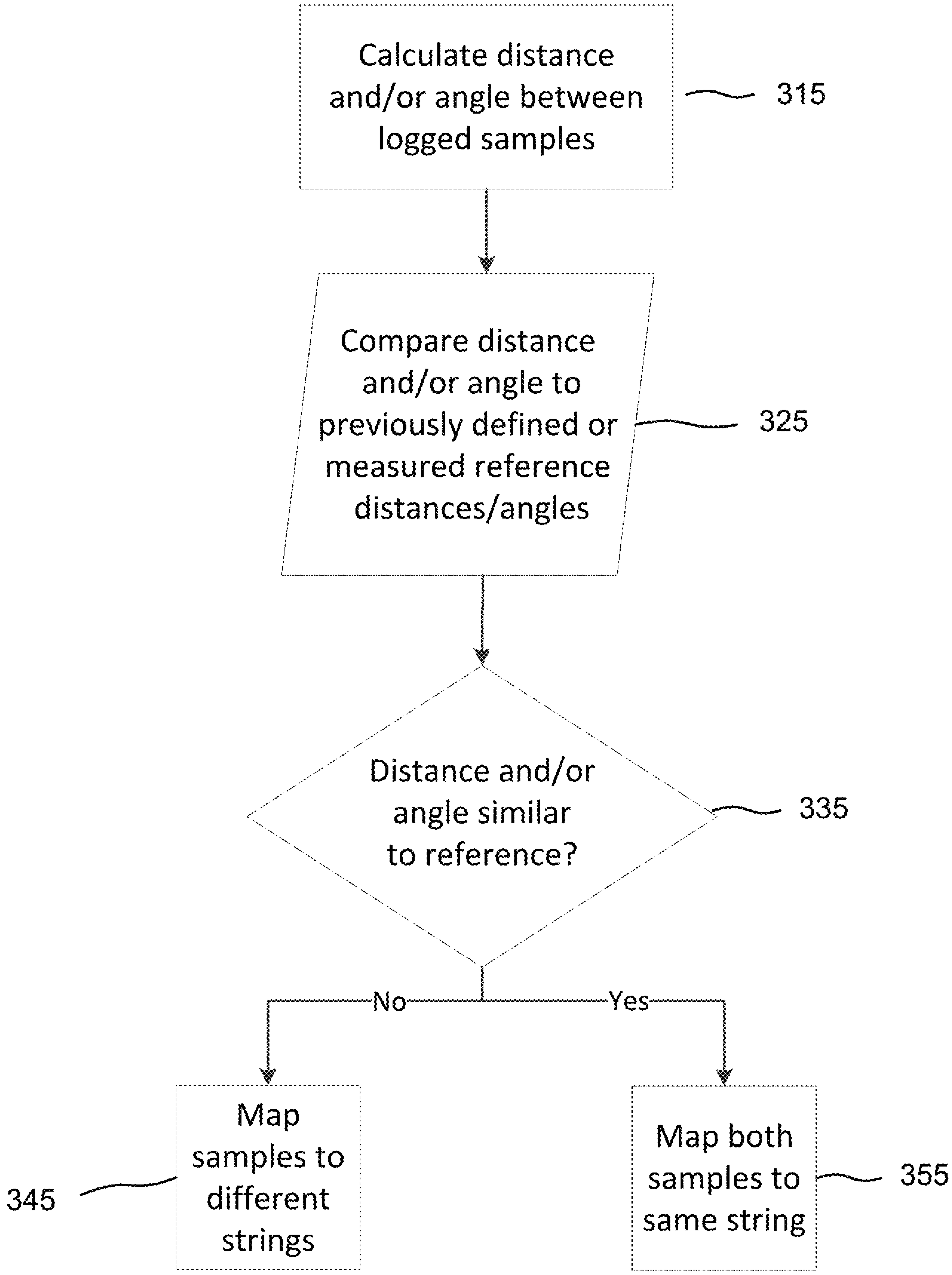

Calculate distance and/or angle between logged samples
315
Compare distance and/or angle to previously defined or measured reference distances/angles
325
Distance and/or angle similar to reference?
335
No
Yes
Map samples to different strings
345
Map both samples to same string
355

Fig. 3B

physical_map.txt

```
Row 1: 20 devices, 1 meter apart
Distance between row 1 and row 2: 4m
Row 2: 20 devices, 1 meter apart
Distance between row 2 and row 3: 4m
Row 2: 30 devices, 1 meter apart
Distance between row 2 and row 3: 8m

•
•
•
```

Example of step 100

Fig. 4

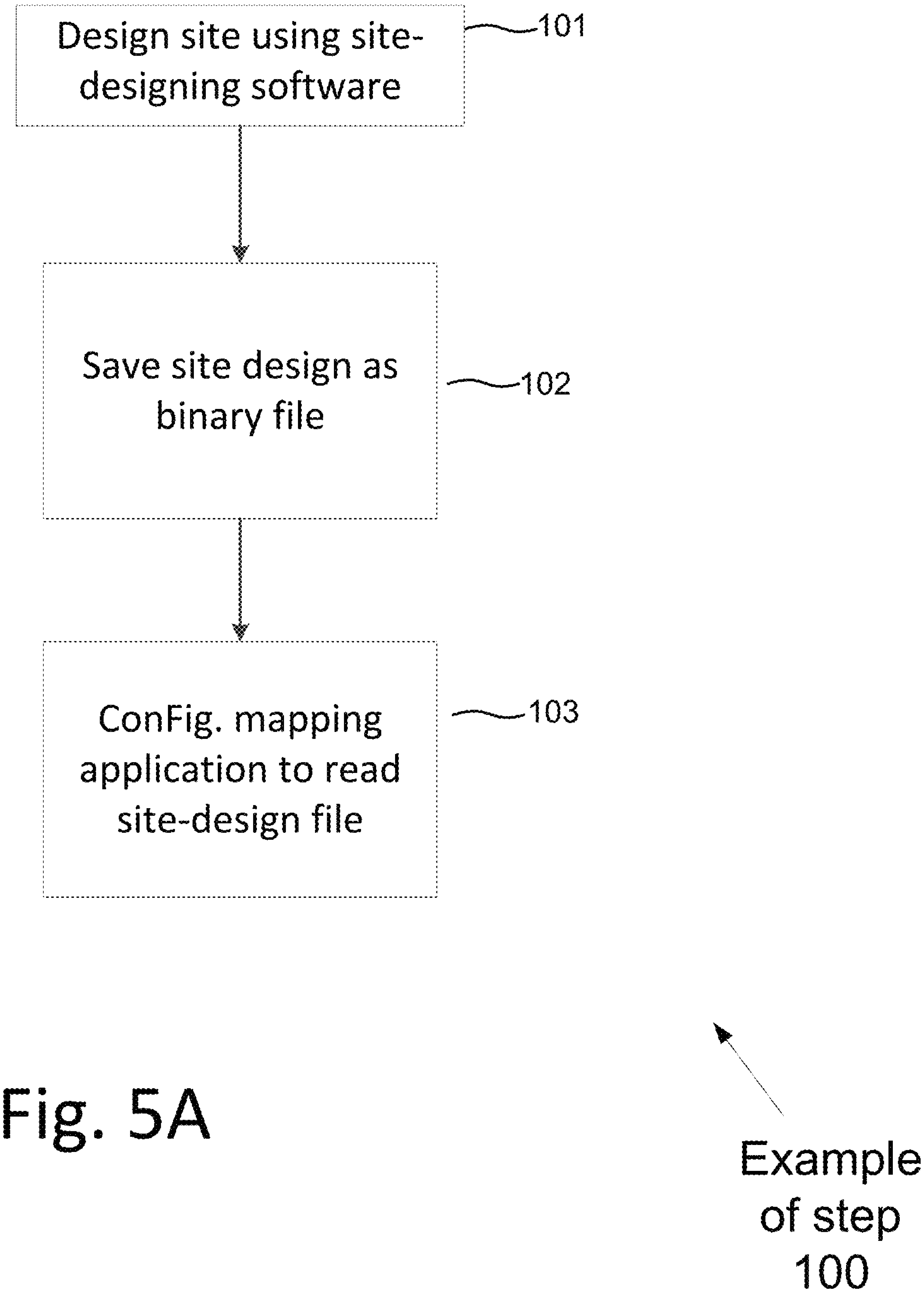

Design site using site-designing software
101
Save site design as binary file
102
ConFig. mapping application to read site-design file
103
Example of step 100

Fig. 5A

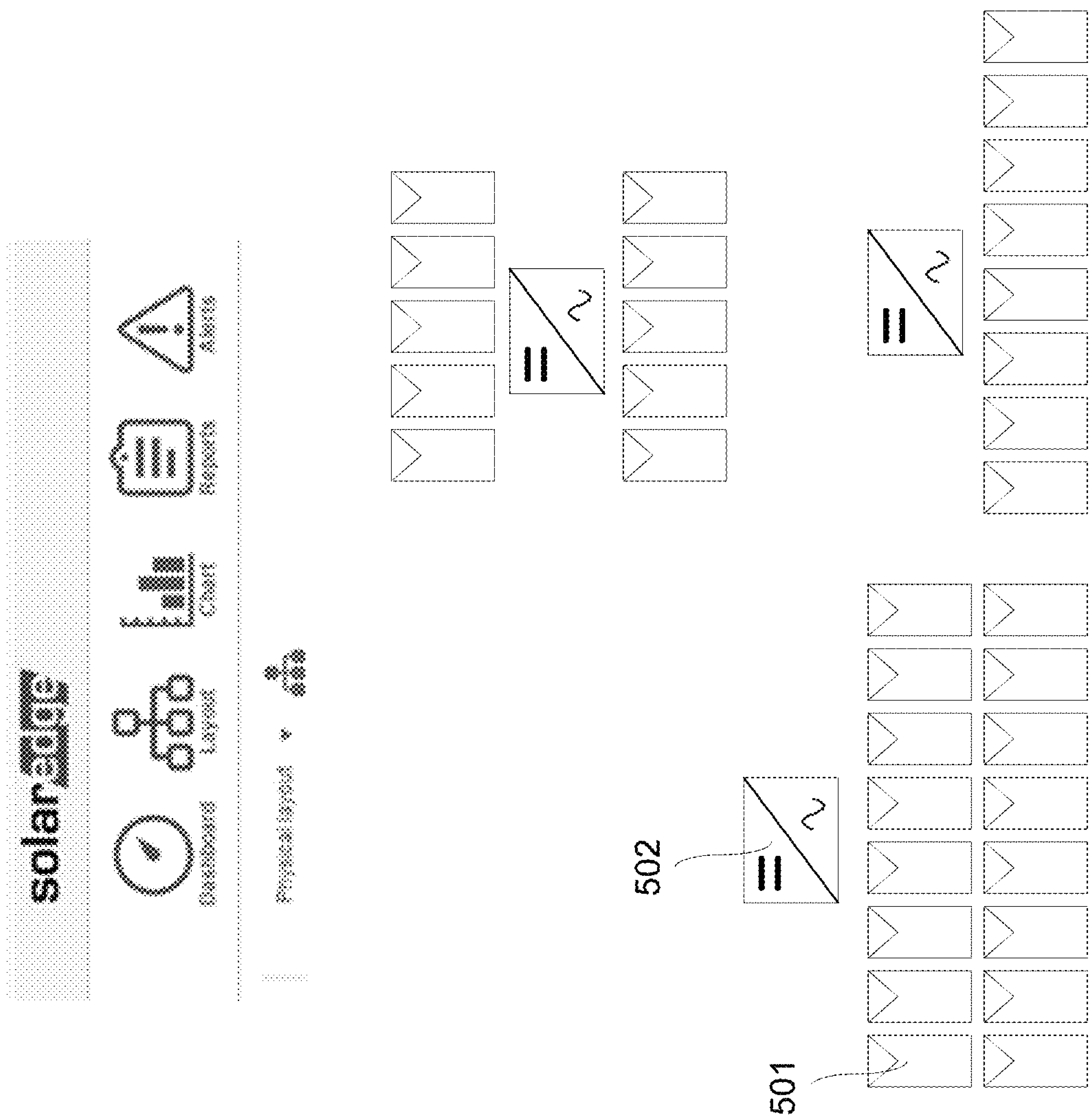


Fig. 5B

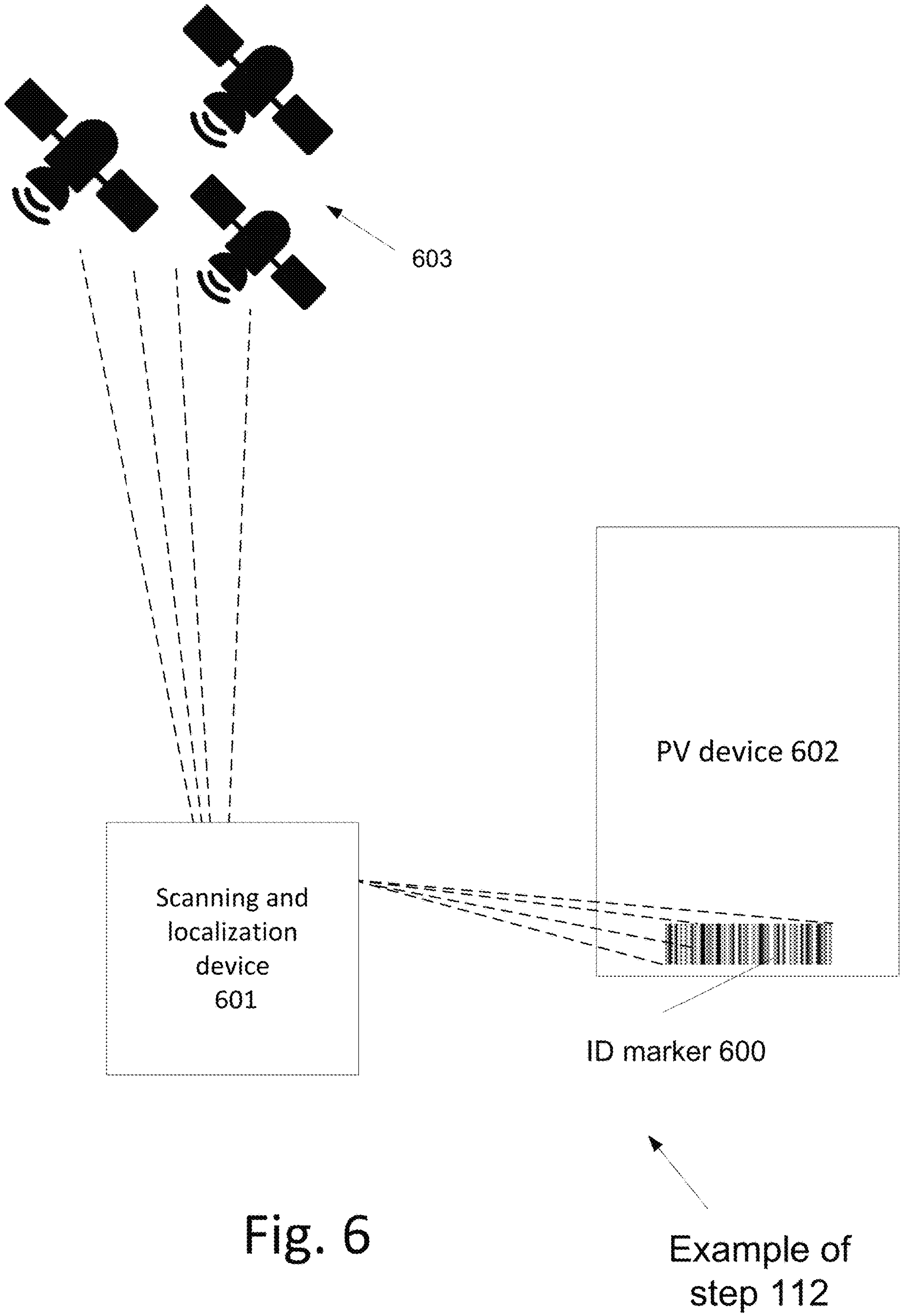

603
PV device 602
Scanning and localization device 601
ID marker 600
Example of step 112

Fig. 6

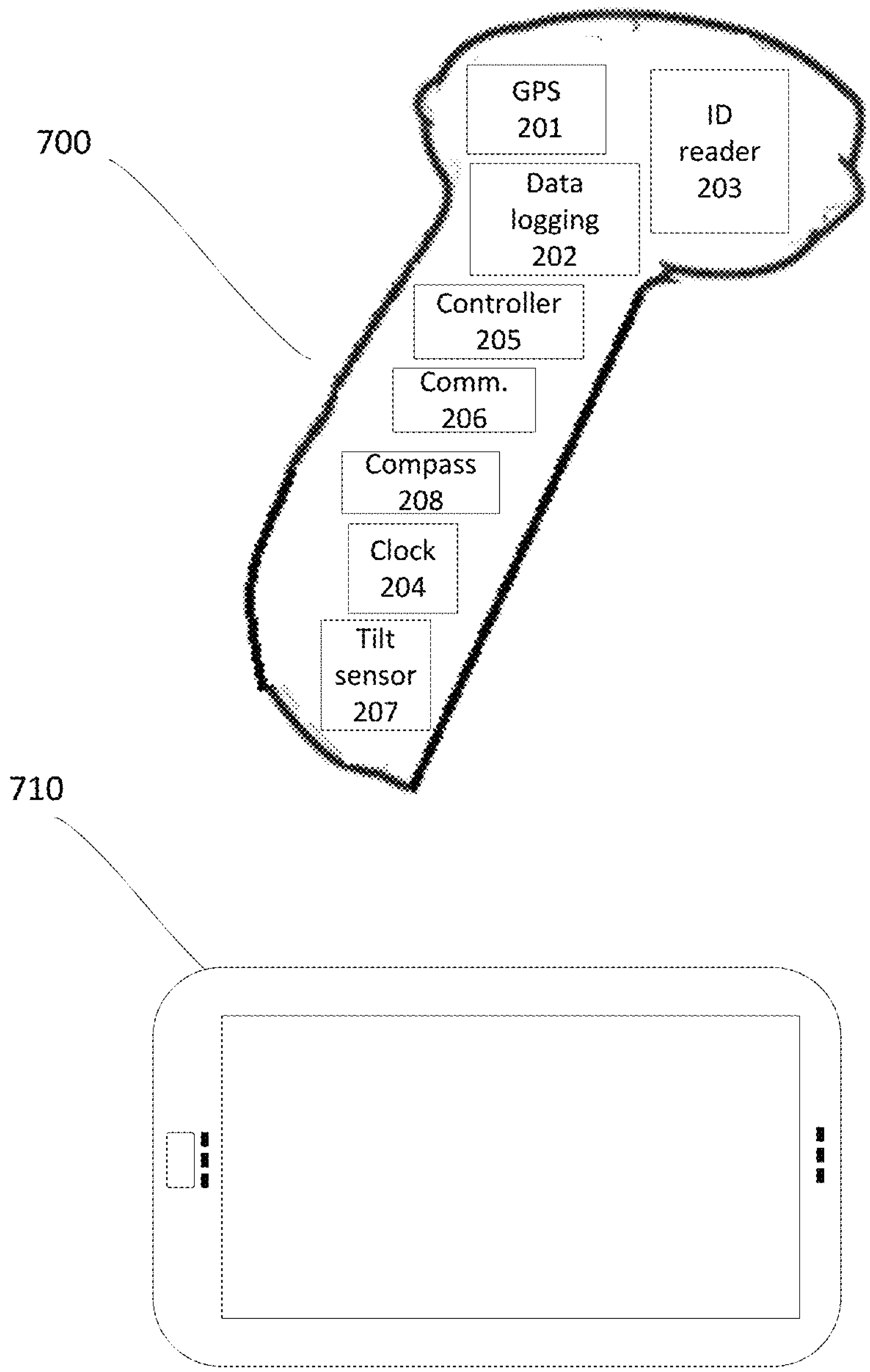

700
GPS 201
ID reader 203
Data logging 202
Controller 205
Comm. 206
Compass 208
Clock 204
Tilt sensor 207
710

Fig. 7

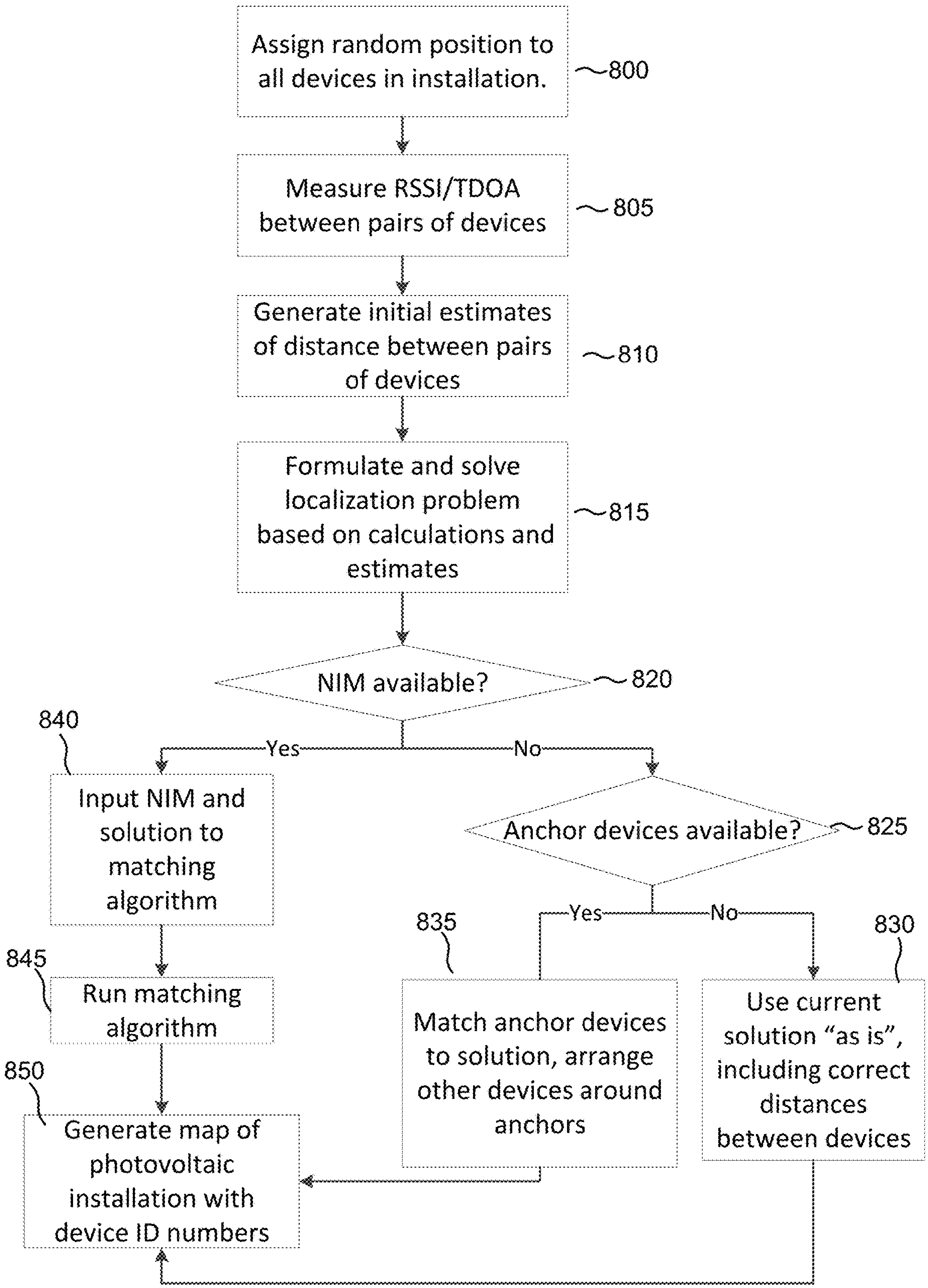

Assign random position to all devices in installation.
800
Measure RSSI/TDOA between pairs of devices
805
Generate initial estimates of distance between pairs of devices
810
Formulate and solve localization problem based on calculations and estimates
815
NIM available?
820
Yes
No
840
Input NIM and solution to matching algorithm
Anchor devices available?
825
Yes
No
835
830
845
Run matching algorithm
Match anchor devices to solution, arrange other devices around anchors
Use current solution "as is", including correct distances between devices
850
Generate map of photovoltaic installation with device ID numbers

Fig. 8A

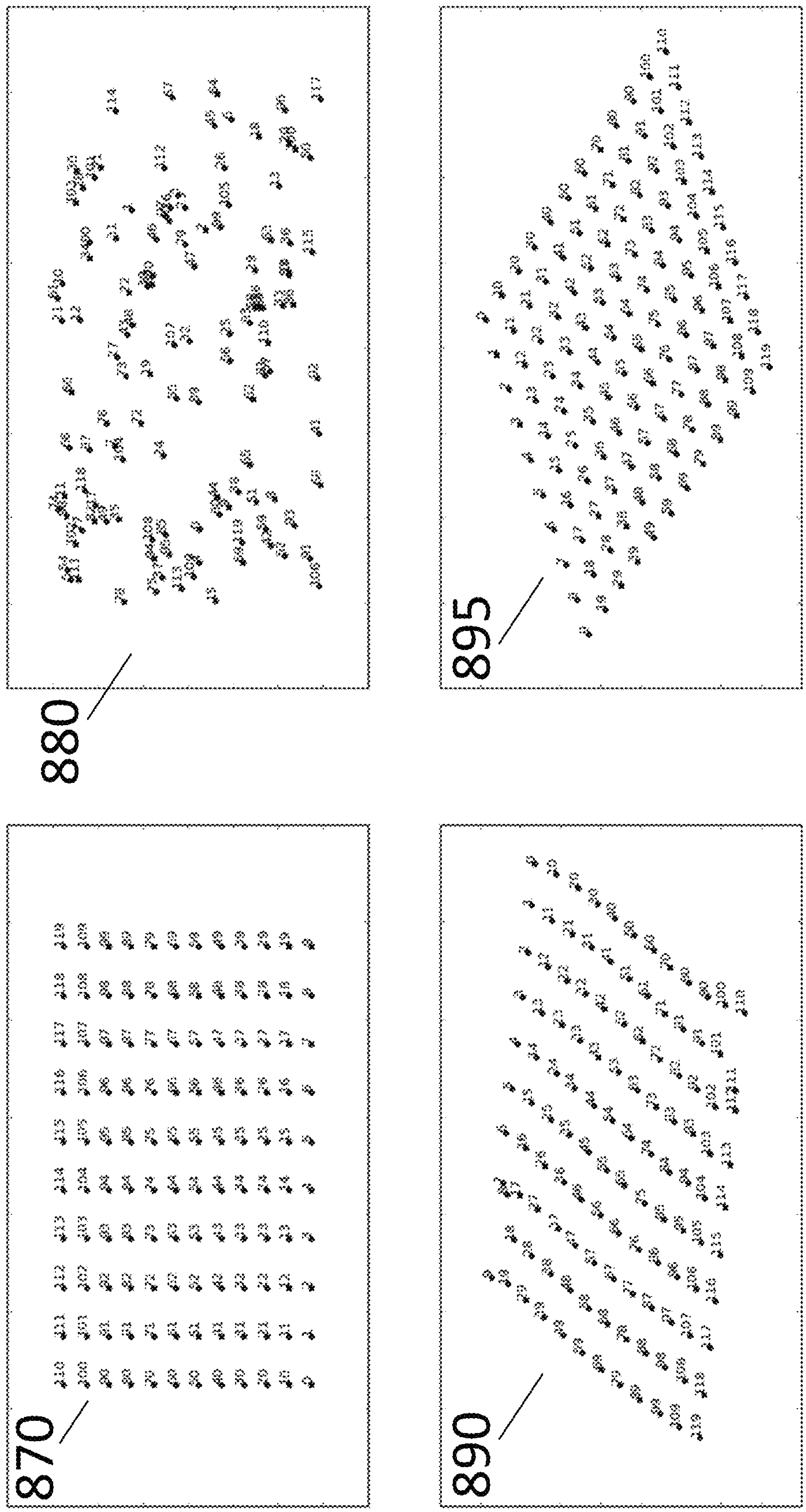


Fig. 8B

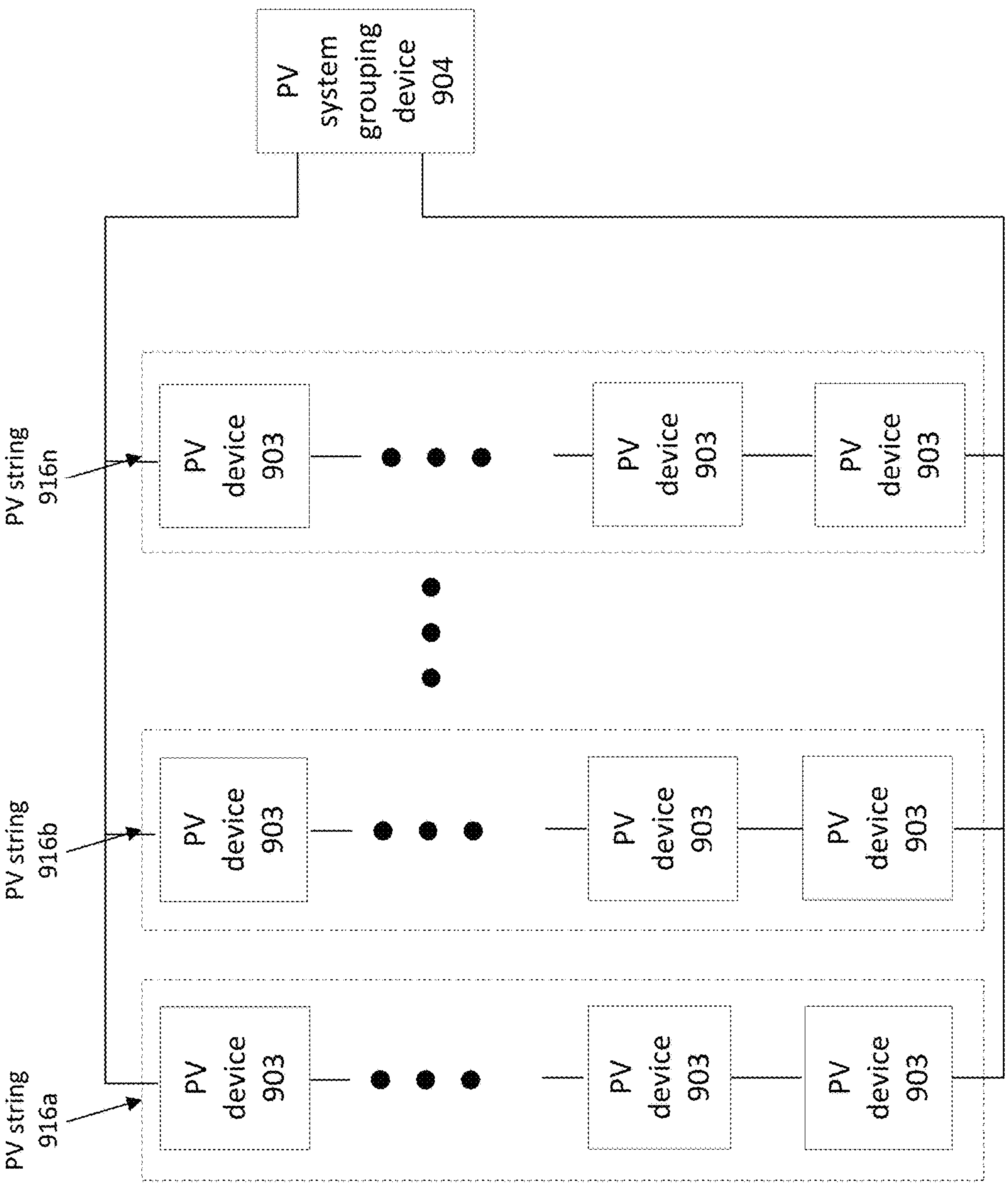

PV system grouping device 904
PV string 916a
PV string 916b
PV string 916n
PV device 903

Fig. 9

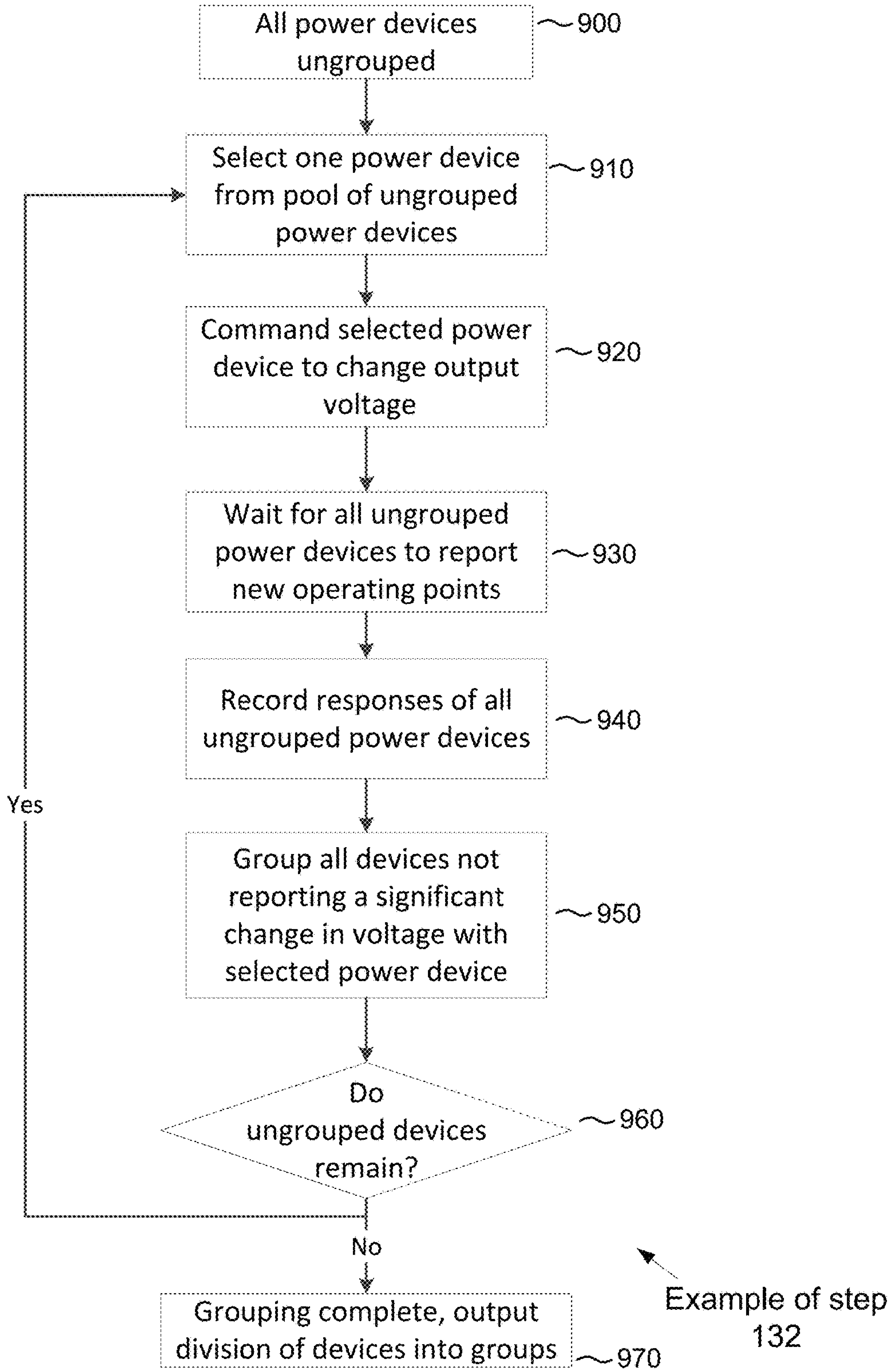
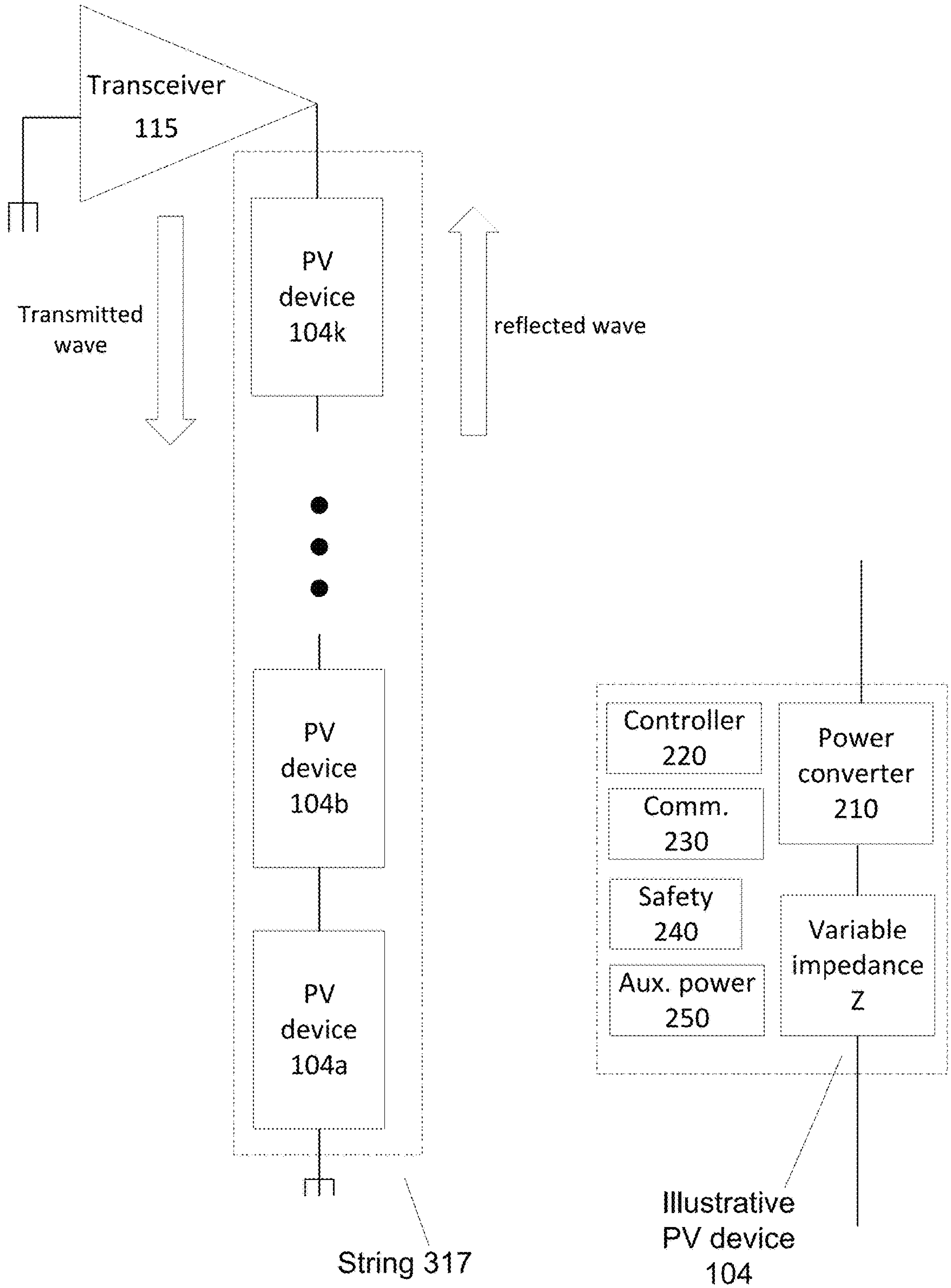

All power devices ungrouped
900
Select one power device from pool of ungrouped power devices
910
Command selected power device to change output voltage
920
Wait for all ungrouped power devices to report new operating points
930
Record responses of all ungrouped power devices
940
Group all devices not reporting a significant change in voltage with selected power device
950
Do ungrouped devices remain?
960
Yes
No
Grouping complete, output division of devices into groups
970
Example of step 132

Fig. 10



Transceiver
115
Transmitted wave
PV device 104k
reflected wave
PV device 104b
PV device 104a
String 317
Controller 220
Comm. 230
Safety 240
Aux. power 250
Power converter 210
Variable impedance Z
Illustrative PV device 104

Fig. 11A

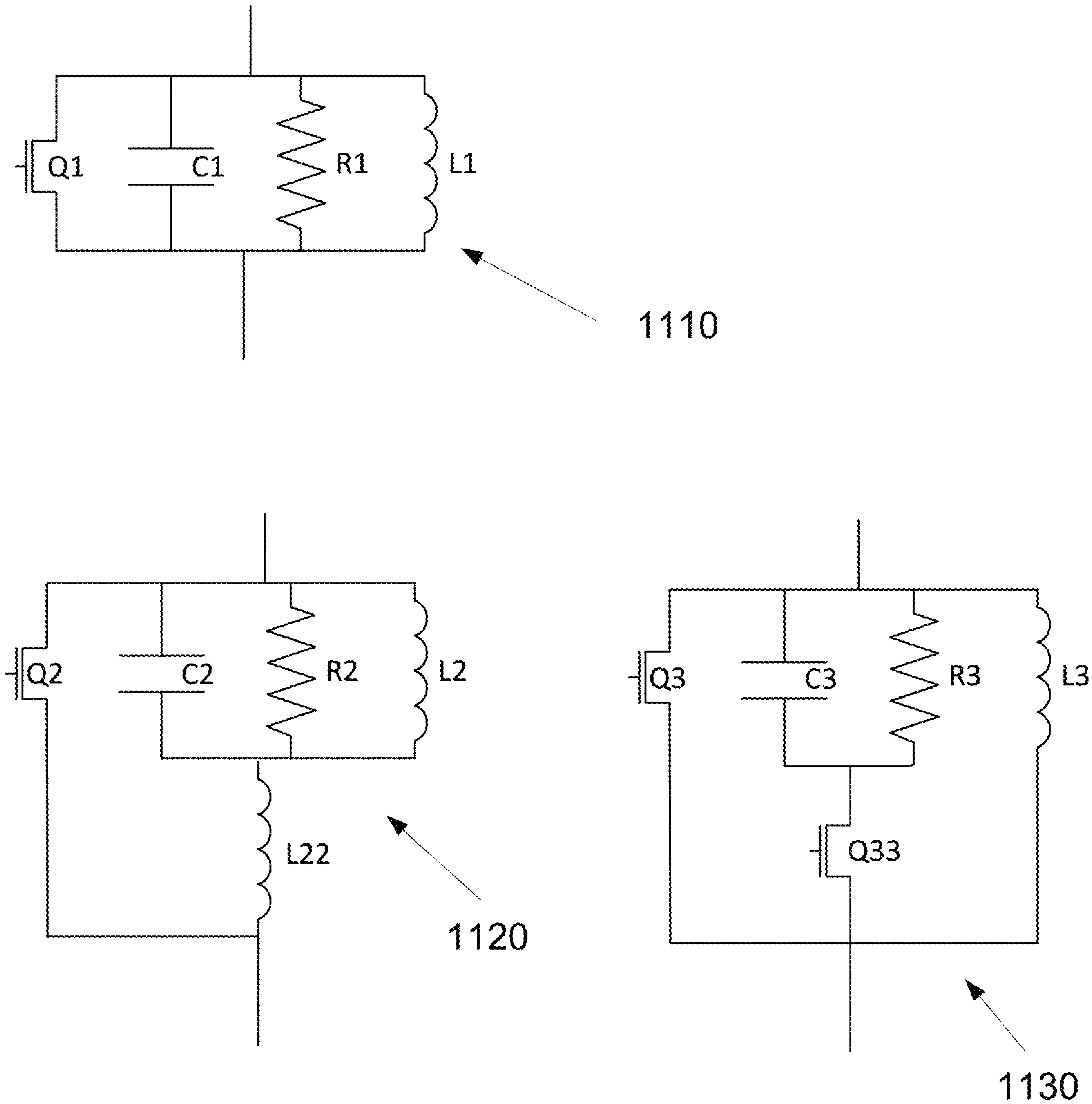


Fig. 11B

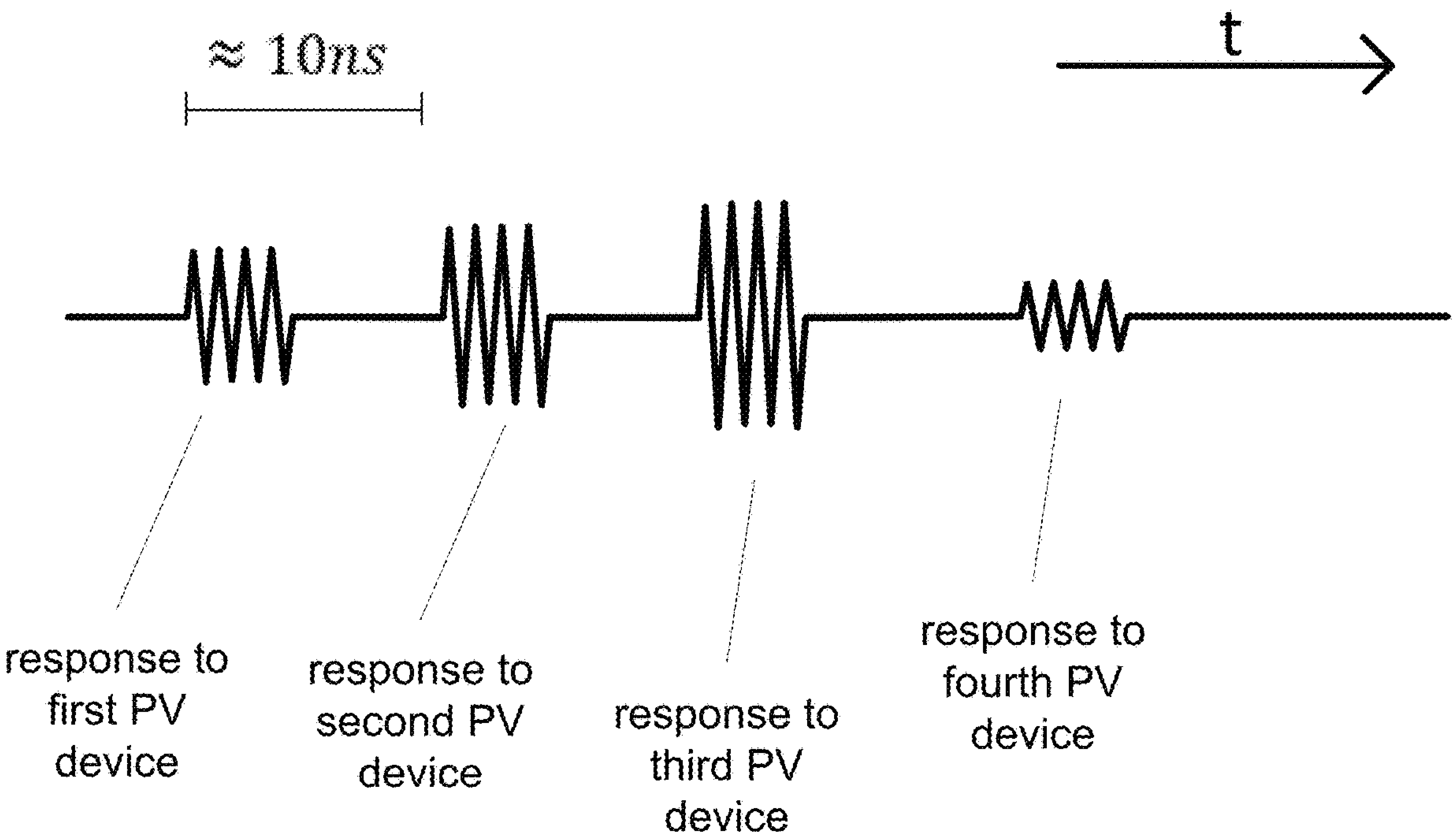

≈ 10ns
t
response to first PV device
response to second PV device
response to third PV device
response to fourth PV device

Fig. 12

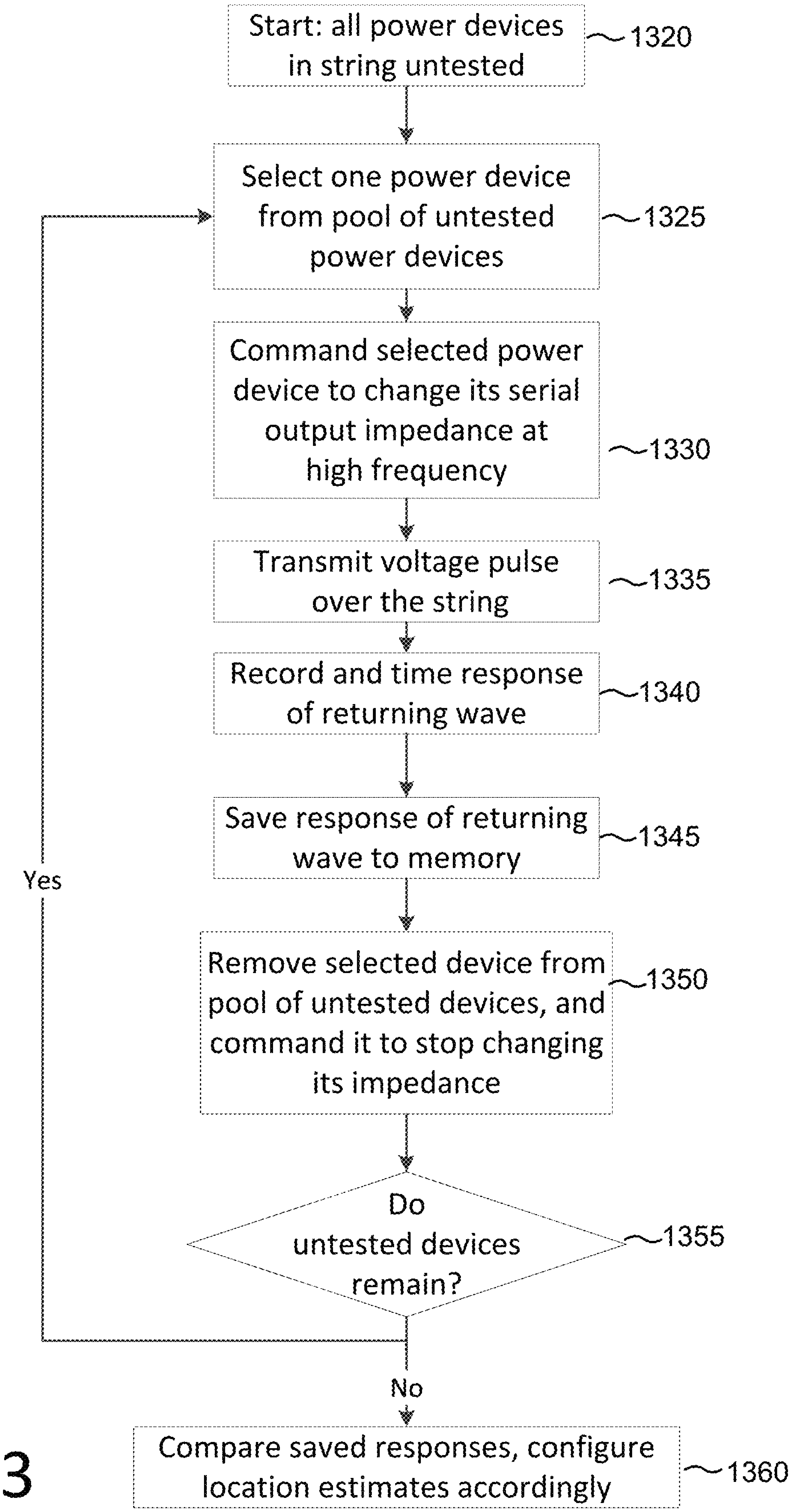

Start: all power devices in string untested
1320
Select one power device from pool of untested power devices
1325
Command selected power device to change its serial output impedance at high frequency
1330
Transmit voltage pulse over the string
1335
Record and time response of returning wave
1340
Save response of returning wave to memory
1345
Remove selected device from pool of untested devices, and command it to stop changing its impedance
1350
Do untested devices remain?
1355
Yes
No
Compare saved responses, configure location estimates accordingly
1360

Fig. 13

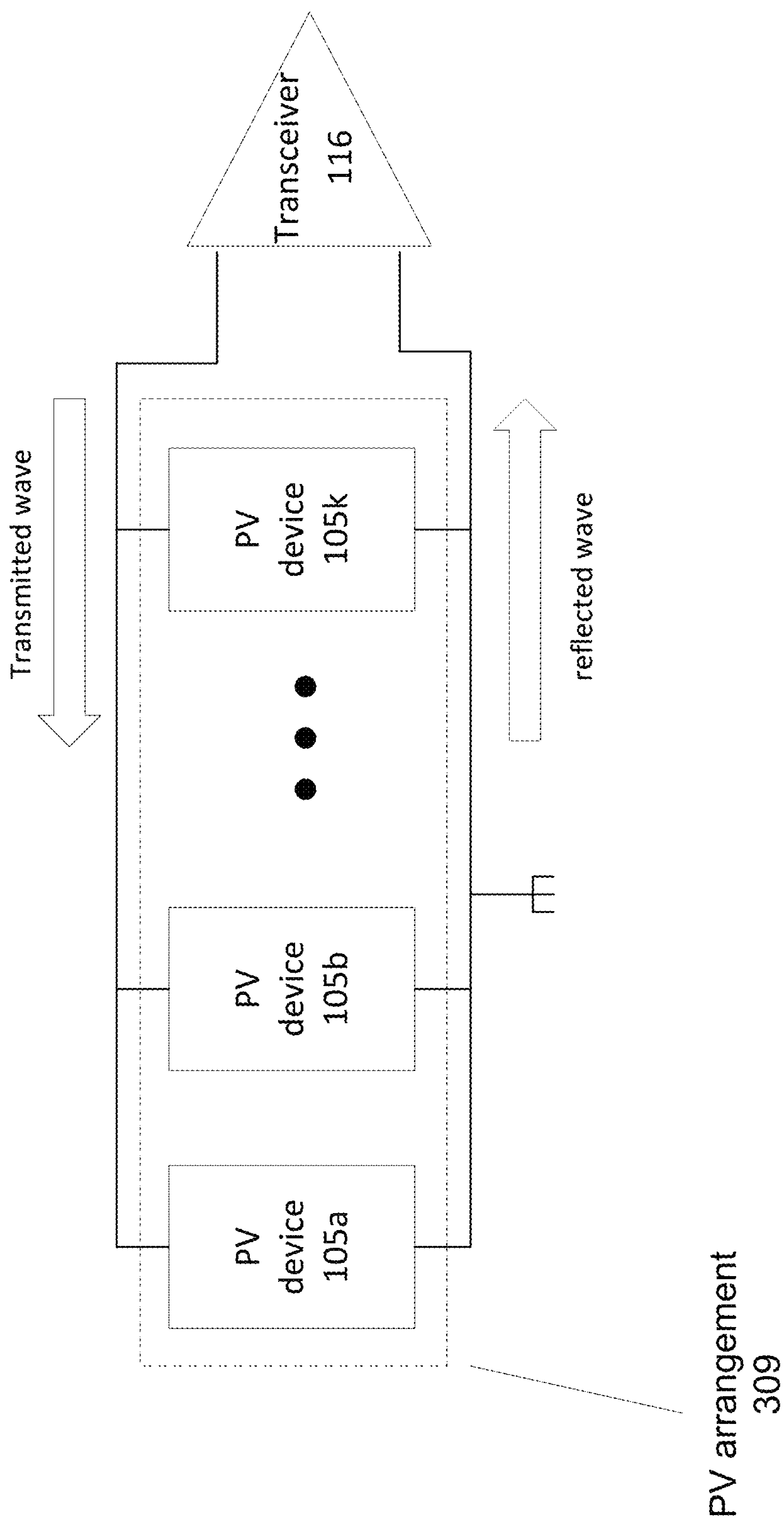

Transceiver
116
Transmitted wave
reflected wave
PV
device
105k
PV
device
105b
PV
device
105a
PV arrangement
309

Fig. 14

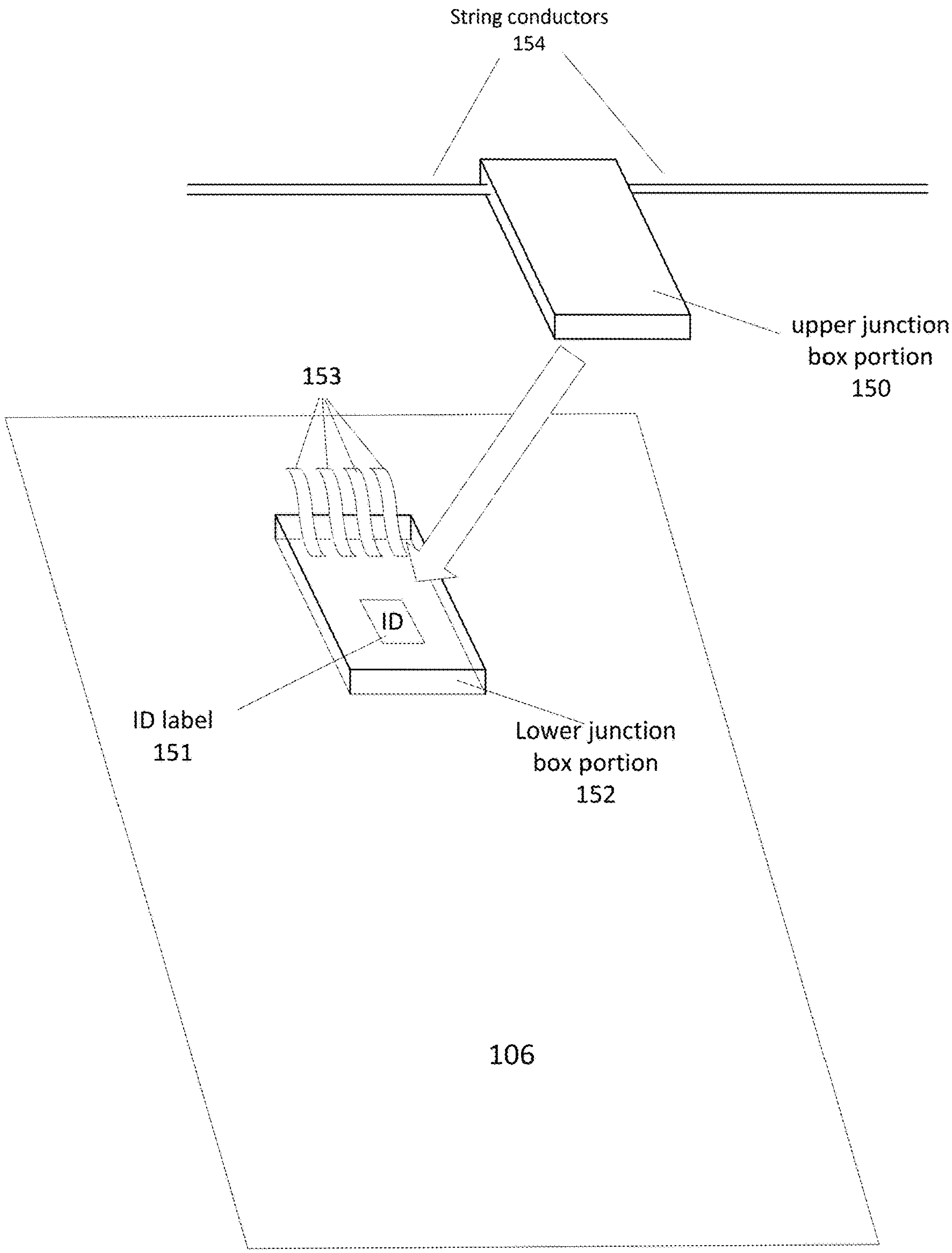

String conductors
154
upper junction
box portion
150
153
ID
ID label
151
Lower junction
box portion
152
106

Fig. 15A

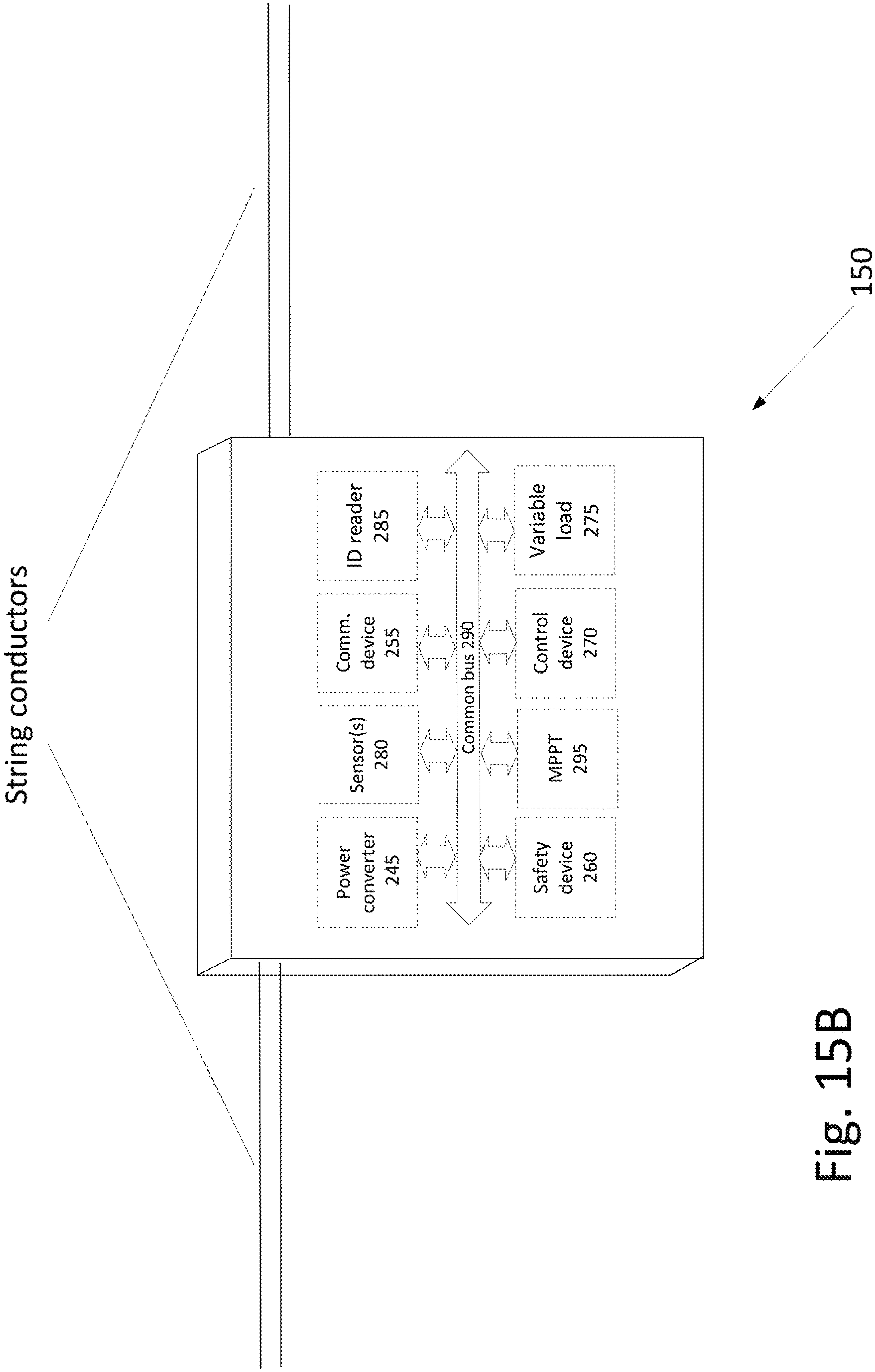

String conductors
150
ID reader 285
Comm. device 255
Sensor(s) 280
Power converter 245
Common bus 290
Variable load 275
Control device 270
MPPT 295
Safety device 260

Fig. 15B

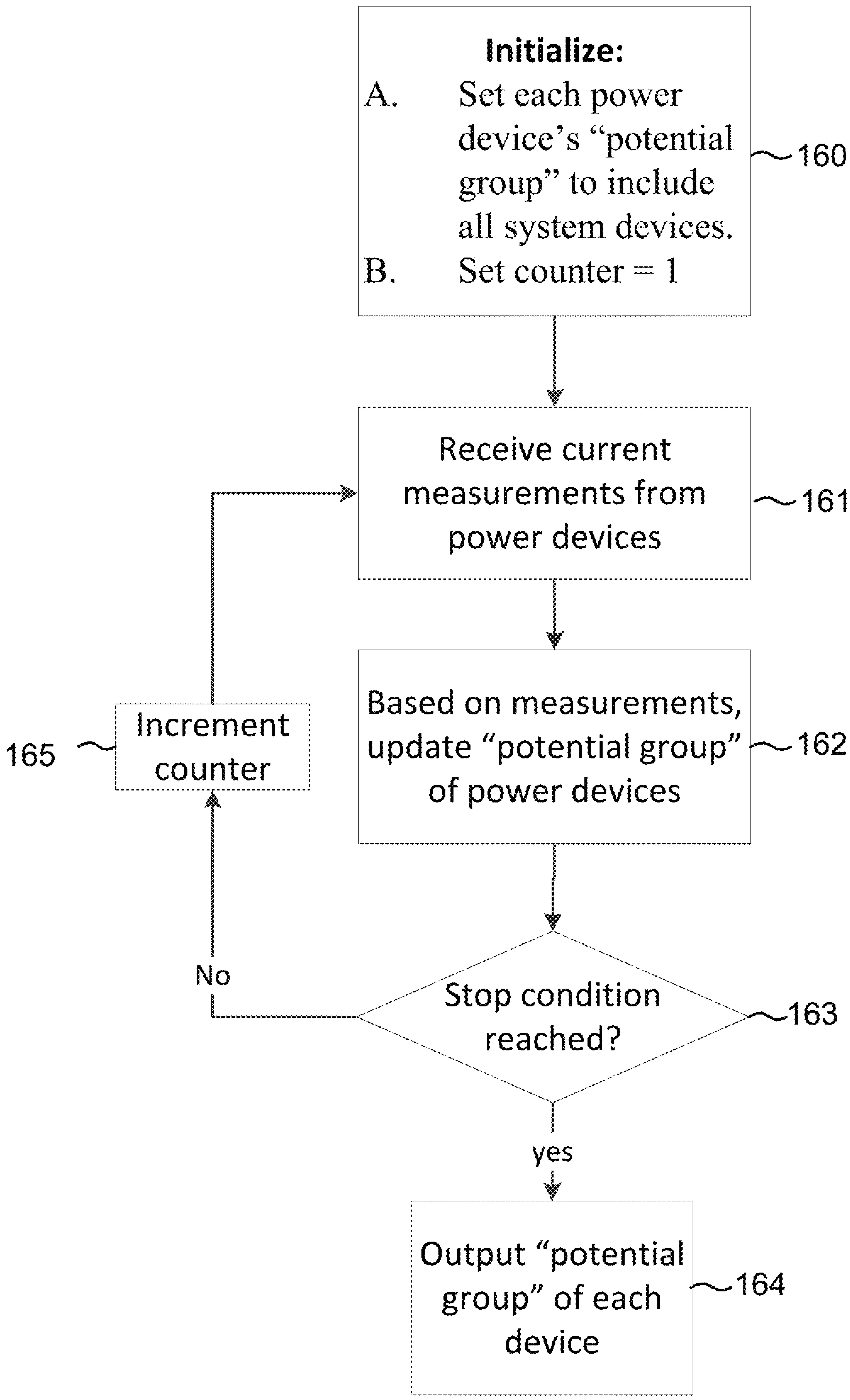

Initialize:
A. Set each power device's "potential group" to include all system devices.
B. Set counter = 1
160
Receive current measurements from power devices
161
Based on measurements, update "potential group" of power devices
162
Increment counter
165
No
Stop condition reached?
163
yes
Output "potential group" of each device
164

Fig. 16

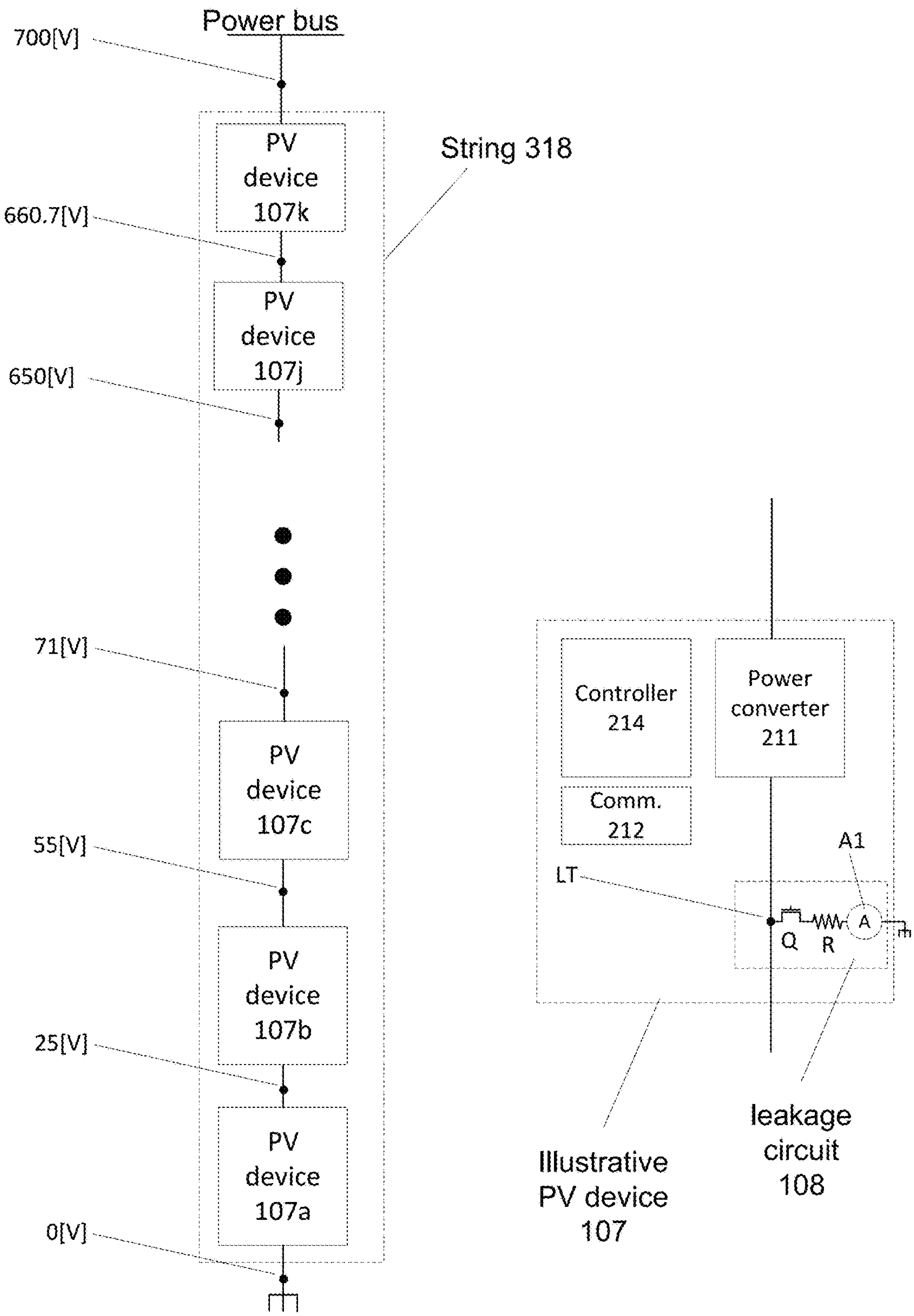

Power bus
700[V]
String 318
PV device 107k
660.7[V]
PV device 107j
650[V]
71[V]
PV device 107c
55[V]
PV device 107b
25[V]
PV device 107a
0[V]
Controller 214
Power converter 211
Comm. 212
A1
LT
A
Q
R
Illustrative PV device 107
leakage circuit 108

Fig. 17A

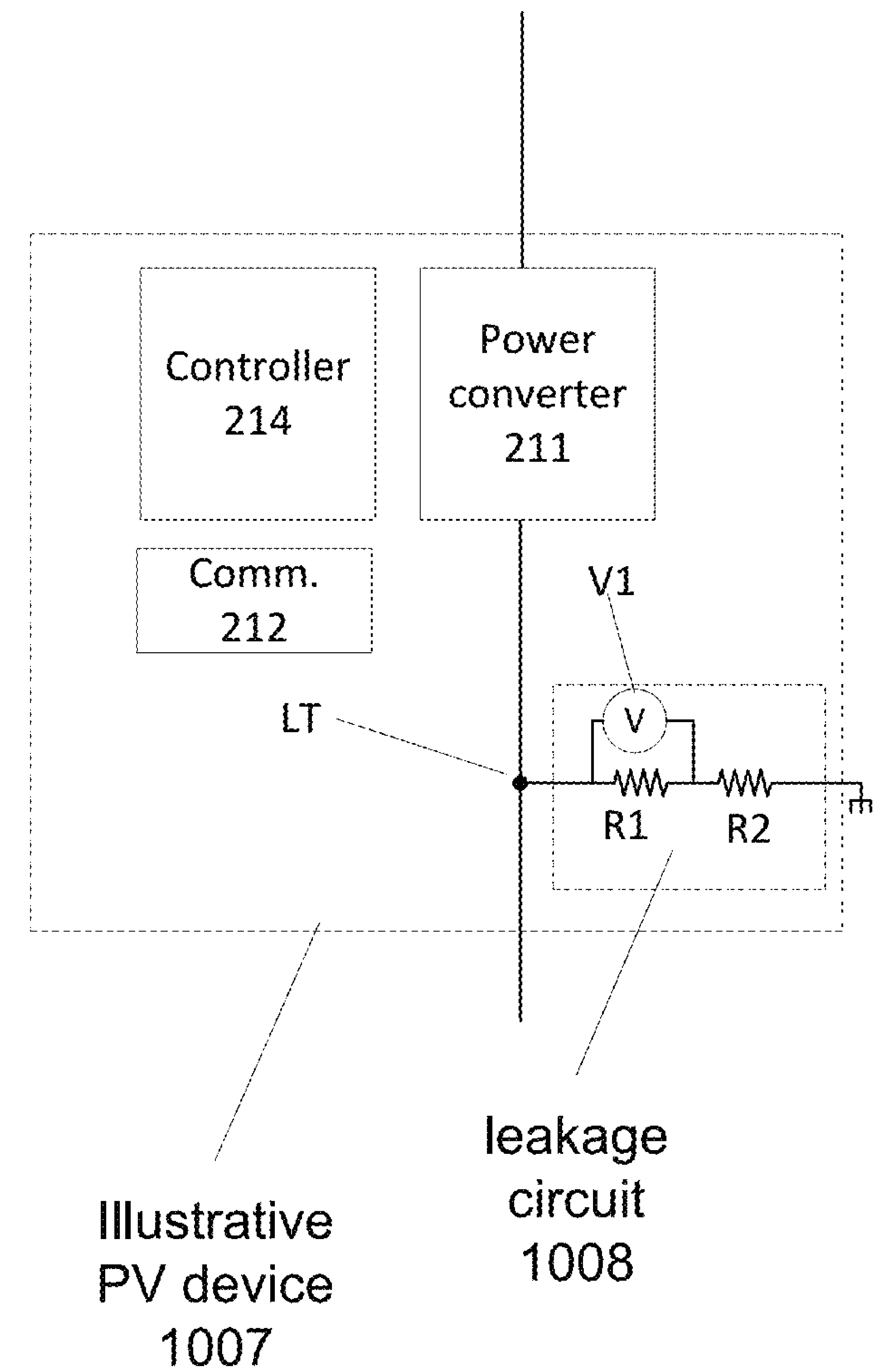

Controller
214
Power
converter
211
Comm.
212
V1
LT
V
R1
R2
leakage
circuit
1008
Illustrative
PV device
1007

Fig. 17B

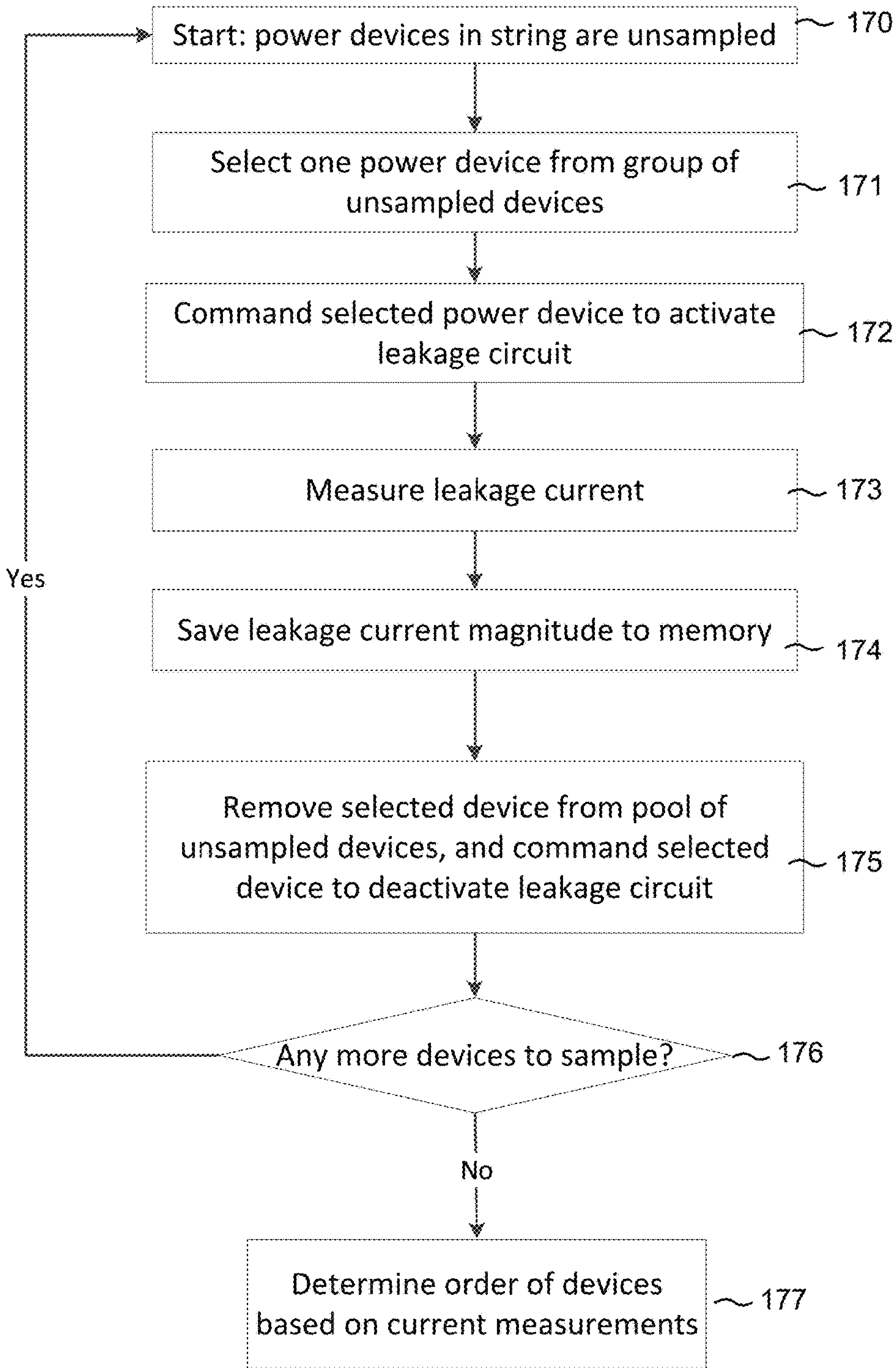

Start: power devices in string are unsampled
170
Select one power device from group of unsampled devices
171
Command selected power device to activate leakage circuit
172
Measure leakage current
173
Save leakage current magnitude to memory
174
Remove selected device from pool of unsampled devices, and command selected device to deactivate leakage circuit
175
Any more devices to sample?
176
Yes
No
Determine order of devices based on current measurements
177

Fig. 18

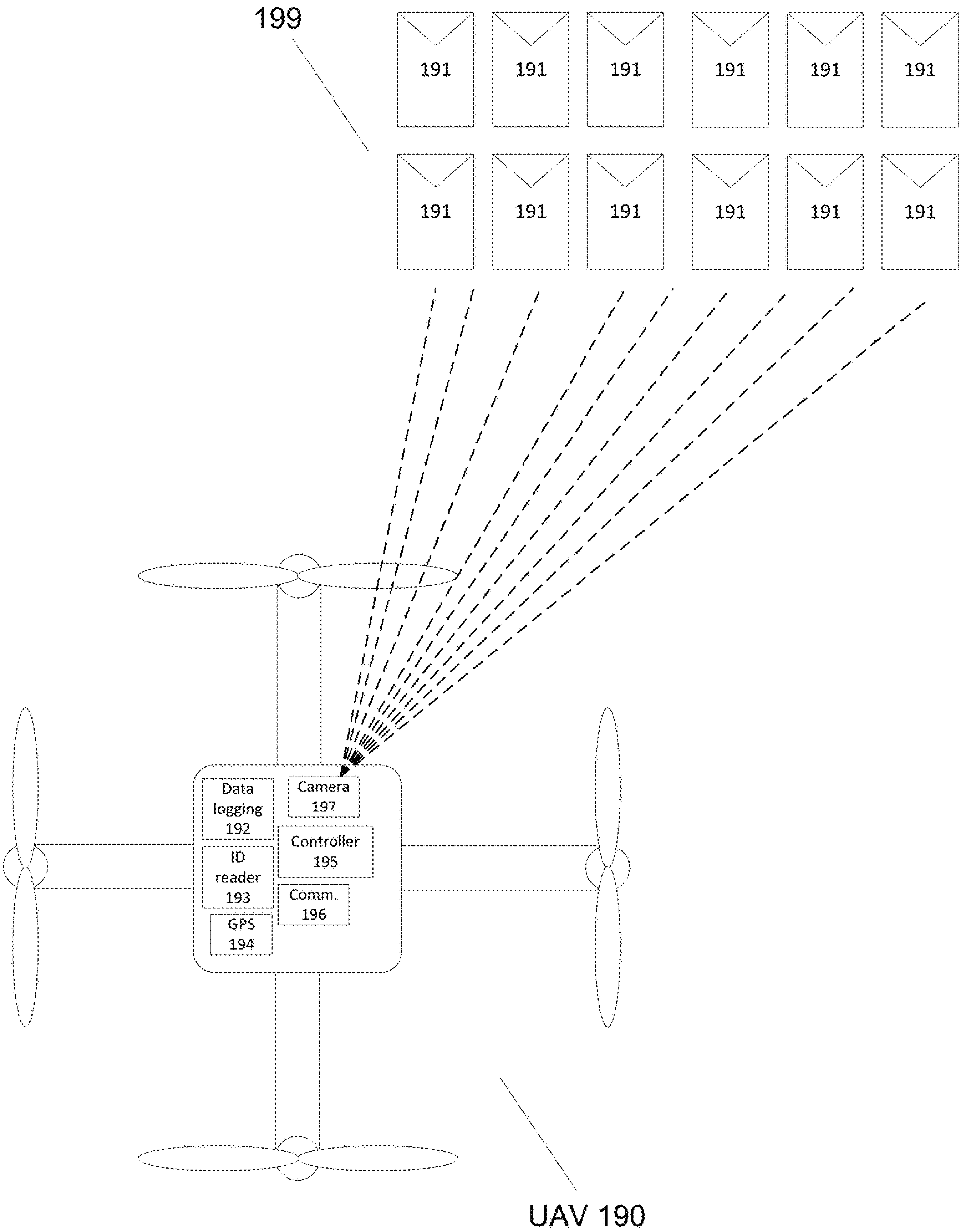

199
191
191
191
191
191
191
191
191
191
191
191
191
Data logging 192
Camera 197
Controller 195
ID reader 193
Comm. 196
GPS 194
UAV 190

Fig. 19

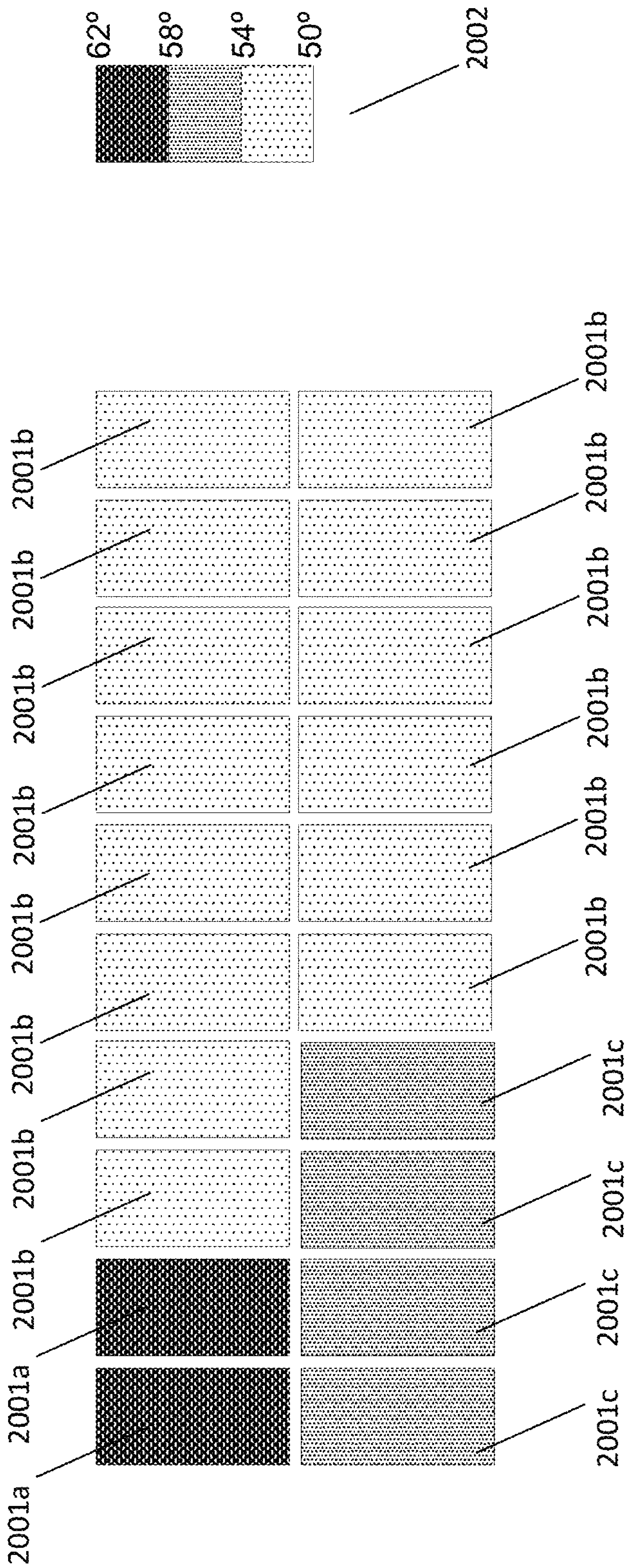

62°
58°
54°
50°
2002
2001a
2001a
2001b
2001b
2001b
2001b
2001b
2001b
2001b
2001b
2001b
2001b
2001b
2001b
2001b
2001b
2001b
2001c
2001c
2001c
2001c

Fig. 20

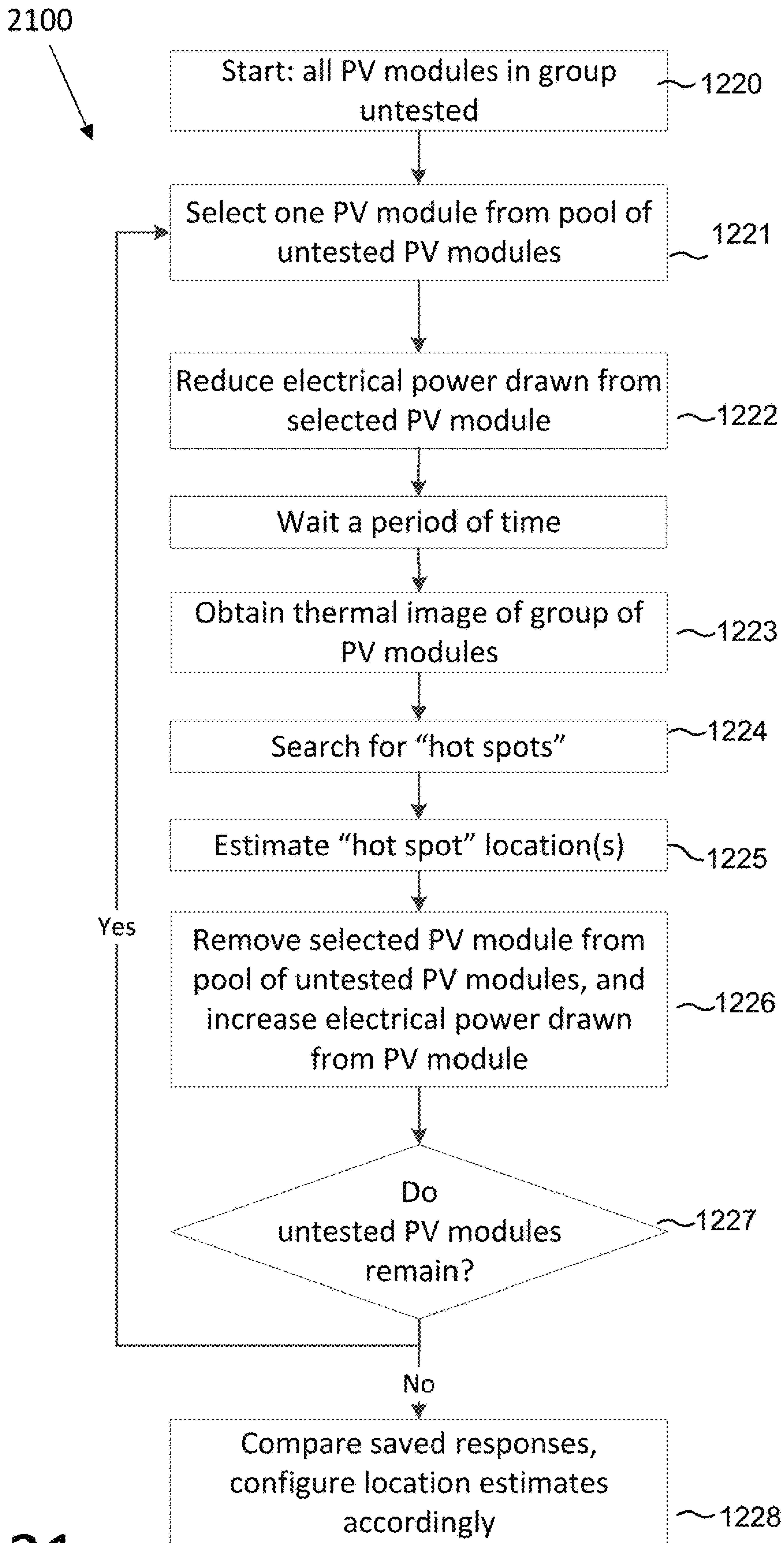

2100
Start: all PV modules in group untested
1220
Select one PV module from pool of untested PV modules
1221
Reduce electrical power drawn from selected PV module
1222
Wait a period of time
Obtain thermal image of group of PV modules
1223
Search for "hot spots"
1224
Estimate "hot spot" location(s)
1225
Yes
Remove selected PV module from pool of untested PV modules, and increase electrical power drawn from PV module
1226
Do untested PV modules remain?
1227
No
Compare saved responses, configure location estimates accordingly
1228

Fig. 21

METHODS FOR MAPPING POWER GENERATION INSTALLATIONS

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a continuation of U.S. patent application Ser. No. 15/447,981, which claims priority to U.S. provisional patent application Ser. No. 62/303,017, filed Mar. 3, 2016, entitled "Methods for Mapping Power Generation Installations," and U.S. provisional patent application Ser. No. 62/381,298, filed Aug. 30, 2016, entitled "Methods for Mapping Power Generation Installations." The above applications are hereby incorporated by reference in their entireties for all purposes.

BACKGROUND

Photovoltaic (PV) installations may include a large number of components and wide variety of devices. A PV installation may include one or more arrays of PV generators (e.g. solar modules, solar cells, solar panels), one or more inverter(s), communication devices, and PV power devices such DC/DC converters, DC-AC microinverters, combiner boxes, and Maximum-Power-Point-Tracking (MPPT) devices. Some installations may further include batteries. Some of the electronic modules may be integrated with the PV modules and may provide other functions such as monitoring of performance and/or protection against theft. In case of the system experiencing power loss or in case of a potentially unsafe condition, it may be desirable for a system maintenance operator to physically locate a particular device (e.g. solar panel, DC-DC converter or micro-inverter) that may be potentially responsible for the power loss or potentially unsafe condition.

Operators and monitoring bodies of PV installations might not always have access to a map which indicates the location of each PV module, identified by a serial number. In such cases, troubleshooting problems may be time consuming, since locating a specific module, e.g., a malfunctioning module, may be difficult. In other instances, a map of the installation may be obtained by significant manual effort, such as a maintenance worker walking through the installation and copying ID numbers off modules, denoting their location on a map. If performed manually, human error may also cause inaccurate information to be recorded in the maps.

There is a need for an automatic or semi-automatic method of generating physical maps of PV installations, to save work and reduce errors, while allowing system monitoring personnel to obtain the benefits of having a map which indicates the locations and ID numbers of PV modules.

SUMMARY

The following summary is a short summary of some of the inventive concepts for illustrative purposes only, and is not intended to limit or constrain the inventions and examples in the detailed description. One skilled in the art will recognize other novel combinations and features from the detailed description.

Embodiments herein may employ methods for generating maps of PV installations. Some illustrative embodiments may be fully automatic, and some may require manual steps.

In illustrative methods, a suitable localization algorithm may be utilized to measure or estimate the global coordinates of photovoltaic (PV) devices, and/or the distance and/or angle between different devices, and/or the distance and/or angle between devices and known locations. Some embodiments may include obtaining the global coordinates of devices. Some embodiments may produce a map displaying the physical placement and location of devices along with identifying information e.g. ID or serial numbers). Some embodiments may utilize high-accuracy Global Positioning System (GPS) technology to map the installation. For example, some illustrative methods may include scanning an identifying barcode on PV devices while using GPS to obtain the global coordinates at each scanned location. In some embodiments, a map not including identifying module information may be further utilized to match specific modules to the measured GPS coordinates. Some embodiments may include PV devices transmitting and receiving wireless signals from one another, and using measured or estimated quantities such as Received Signal Strength Indication (RSSI), Angle of Arrival (AOA, also known as Direction of Arrival, or DOA) and/or Time Difference of Arrival (TDOA) to estimate relative distances and/or angles between modules. In some embodiments, Power Line Communication (PLC) methods may be used along with Time Domain Reflection (TDR) techniques to estimate the location of a set of PV devices within a PV installation. The set of estimates may be processed to obtain an accurate physical map of the installation, including identifying where each PV module and/or PV device is physically located.

In other illustrative methods, photovoltaic modules may be operated to increase and decrease the electrical power produced by the photovoltaic modules, which may result in a change of temperature at the photovoltaic modules. A thermal imaging device may be used to capture thermal images of a group of photovoltaic modules under different power production and temperature conditions, and suitable methods may analyze and aggregate the thermal images to obtain an accurate physical map of the installation.

As noted above, this summary is merely a summary of some of the features described herein. It is not exhaustive, and it is not to be a limitation on the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects, and advantages of the present disclosure will become better understood with regard to the following description, claims, and drawings. The present disclosure is illustrated by way of example, and not limited by, the accompanying figures. A more complete understanding of the present disclosure and the advantages thereof may be acquired by referring to the following description in consideration of the accompanying drawings, in which like reference numbers indicate like features, and wherein:

FIG. **1** is a flow diagram of a method for generating a photovoltaic (PV) installation map according to one or more illustrative aspects of the disclosure.

FIG. **2**A is a flow diagram of a method for fitting measured locations to a map according to one or more illustrative aspects of the disclosure.

FIG. **2**B illustrates a non-identifying map (NIM) according to one or more illustrative aspects of the disclosure.

FIG. **2**C illustrates an estimated layout map (ELM) according to one or more illustrative aspects of the disclosure.

FIG. **2**D illustrates how illustrative methods may be applied to illustrative PV systems according to one or more illustrative aspects of the disclosure.

FIG. **3**A is a flow diagram of a method for generating an installation map based on time and location according to one or more illustrative aspects of the disclosure.

FIG. **3**B is a flow diagram of a method for mapping samples to strings according to one or more illustrative aspects of the disclosure.

FIG. **4** illustrates an illustrative of representing and storing a Non-identifying Map according to one or more illustrative aspects of the disclosure.

FIG. **5**A is a flow diagram of a method for generating a Non-Identifying Map according to one or more illustrative aspects of the disclosure.

FIG. **5**B illustrates a user interface for PV installation mapping according to one or more illustrative aspects of the disclosure.

FIG. **6** illustrates an illustrative embodiment of reading identifying information from a PV device and estimating the device location according to one or more illustrative aspects of the disclosure.

FIG. **7** illustrates illustrative devices which may be used for reading identifying information and/or estimating device location according to one or more illustrative aspects of the disclosure.

FIG. **8**A is a flow diagram of a method for installation mapping according to one or more illustrative aspects of the disclosure.

FIG. **8**B illustrates results of various stages of installation mapping according to one or more illustrative aspects of the disclosure.

FIG. **9** is part-block diagram, part schematic of an illustrative PV installation that may be mapped according to one or more illustrative aspects of the disclosure.

FIG. **10** is a flow diagram of a method for grouping power devices into groups according to one or more illustrative aspects of the disclosure.

FIG. **11**A is a part-block diagram, part-schematic of PV system components which may be used in conjunction with methods described herein.

FIG. **11**B is a schematic of illustrative variable impedance circuits according to one or more illustrative aspects of the disclosure.

FIG. **12** illustrates an illustrative form of a wave reflected off a transmission line according to one or more illustrative aspects of the disclosure.

FIG. **13** is a flow diagram of a method for testing power devices according to one or more illustrative aspects of the disclosure.

FIG. **14** is a part-block diagram, part-schematic of a PV arrangement, comprising PV system components, which may be used in conjunction with methods described herein.

FIG. **15**A is a part-block diagram, part-schematic of a PV panel and PV system components which may be used in conjunction with methods described herein.

FIG. **15**B is a part-block diagram, part-schematic of PV system components which may be used in conjunction with methods described herein.

FIG. **16** is a flow diagram of a method for grouping power devices into strings according to one or more illustrative aspects of the disclosure.

FIG. **17**A illustrates an illustrative PV string of PV devices according to one or more illustrative aspects of the disclosure.

FIG. **17**B illustrates an illustrative current leakage circuit according to one or more illustrative aspects of the disclosure.

FIG. **18** is a flow diagram of a method for determining the order of power devices within a PV string according to one or more illustrative aspects of the disclosure.

FIG. **19** illustrates illustrative devices which may be used for reading identifying information and/or estimating device location according to one or more illustrative aspects of the disclosure.

FIG. **20** illustrates a thermal image of a group of photovoltaic modules according to one or more illustrative aspects of the disclosure.

FIG. **21** is a flow diagram of a method for determining relative locations of one or more PV modules within a group of PV modules according to one or more illustrative aspects of the disclosure.

DETAILED DESCRIPTION

In the following description of various illustrative embodiments, reference is made to the accompanying drawings, which form a part hereof, and in which is shown, by way of illustration, various embodiments in which aspects of the disclosure may be practiced. It is to be understood that other embodiments may be utilized and structural and functional modifications may be made, without departing from the scope of the present disclosure.

Monitoring of PV installations may include data collected by a central control system which monitors the power output by the PV installation and identifies potentially problematic operating conditions or safety hazards. When the installation experiences power loss, it may be desirable to ascertain whether it is due to environmental conditions or from malfunctions and/or poor maintenance of the components of the PV installation. Furthermore, it may be desirable to easily physically locate the particular module (e.g. solar panel, DC-DC converter or micro-inverter, combiner box) that may be responsible for the power loss. A map of the PV installation which displays the physical location of the various PV modules or devices (identified by ID numbers, for example) comprising the installation may assist in rapid location of the desired module and fast resolution of the problem. For example, in case of a decrease in the power output by a PV panel, a power device coupled to the panel may send information to a centralized control unit reporting the loss of power. The information may be transmitted using power line communications, wireless communication, acoustic communication or other protocols, and may include the ID number of the PV device. If the low power output persists, a maintenance worker may need to physically go to the underperforming panel and investigate the reason behind the low power.

A Physical Identification Map (PIM) may refer to a physical map indicating the location of modules within a photovoltaic (PV) installation, including attaching identifying information such as serial or ID numbers to some or all of the modules displayed in the map. A Non-Identifying Map (NIM) may refer to a map that describes the location of modules but does not identify a specific module at each location.

FIG. **1** is a flow diagram of a method for generating a PV installation map according to one or more illustrative aspects of the disclosure. In one or more embodiments, the method of FIG. **1**, or one or more steps thereof, may be performed by one or more computing devices or entities. For example, portions of the method of FIG. **1** may be performed by components of a computer system. The method of FIG. **1**, or one or more steps thereof, may be embodied in computer-executable instructions that are stored in a computer-readable medium, such as a non-transitory computer-readable medium. The steps in the method of FIG. **1** might not all be performed in the order specified and some steps may be omitted or changed in order.

At step **100**, an initial map of a PV installation layout may be created. The initial map may be a physical map. For example, at step **100**, measured Global Positioning System (GPS) coordinates may be used to match modules to physical locations on a PIM. The initial map may be created and represented in various ways. In one implementation, the initial map may be represented as a text file which includes information regarding the number of devices, the number of rows, the distances between devices, the distances between rows, or any other information relevant to the physical layout of the installation. In another implementation, the basic map may be automatically generated by installation-design software, and the layout information may be encoded in a digital file generated by the installation-design software.

In some embodiments, step **100** might not be performed. For example, step **100** might not be performed if there is high enough accuracy in other steps of the method to compensate for the lack of an initial map.

In steps **110-13**, power modules in the PV installation may be scanned. For example, the power modules may be scanned by rows. At step **110** each device in a row of the PV installation may be scanned. The scanning may be carried out using a locating device that combines scanning capabilities with a GPS receiver. The locating device may further include one or more of a clock, memory, communication means and a processing unit. Scanning may comprise utilizing a barcode reader to read a barcode which is attached to the module being scanned (e.g. a barcode on a sticker which is stuck to the module), utilizing a camera to identify serial numbers, obtaining identifying information from an RFID tag, or any combinations thereof. The locating device may be a smartphone running an application which combines barcode reading or serial number identifying with GPS localization. The scanning may comprise taking a picture of an identifying element of the module (e.g. an identification sticker) which can later be processed to identify the module based on the picture. In some embodiments, in step **111** the user may conFig. the device (e.g. by press of a button) at the start of each row to begin logging a row of the installation. In some embodiments, the locating device may use time or spatial differences between scans to determine when a new row is being scanned. For example, if a time between scans is above a certain threshold, the locating device may determine that a new row is being scanned.

At step **112** each PV device in the current row may be scanned. Each time a device is scanned, the module's identifying information (e.g. barcode, ID number, picture, RFID tag) as well as the UPS coordinates of the locating device at the time of scanning may be logged and stored into memory. The identifying information corresponding to a device may be unique. A timestamp of the time of scanning may also be logged or stored.

At step **113** it may be determined if all rows of the installation have been scanned. For example, it may be determined if all rows within a specified area have been scanned. If all rows have been scanned, the method may proceed to step **120**. Otherwise, steps **110-13** may be repeated. Steps **110-13** may be repeated until all rows of the installation, or all devices within the installation, have been scanned.

At step **120**, the data (e.g. coordinates, timestamps) collected during steps **110-13** may be collected and input to a matching algorithm. The map created in step **100** may also be input to the matching algorithm.

At step **130**, the matching algorithm may be run by an appropriate computing device, such as a computer, server, DSP, microcontroller, ASIC or FPGA. The algorithm may use the inputted data and/or the map to determine which PV module is located at each of the locations indicated on the map. FIG. **2**A, further described below, is an example of a method that may be used by a matching algorithm at step **130**.

At step **140**, the matching algorithm may generate, based on the input received at step **120**, a map of the PV installation. The map may comprise one or more module identifiers. The module identifiers may be associated with a location in the map. For example, the algorithm may output a map with module identification information being displayed at each module's location. The map may be physically printed onto a sheet of paper, or viewed on an appropriate electronic device such as a computer monitor, tablet or smartphone.

FIG. **2**A is a flow diagram of a method for fitting measured locations to a map according to one or more illustrative aspects of the disclosure. In one or more embodiments, the method of FIG. **2**A, or one or more steps thereof, may be performed by one or more computing devices or entities. For example, portions of the method of FIG. **2**A may be performed by components of a computer system. The method of FIG. **2**A, or one or more steps thereof, may be embodied in computer-executable instructions that are stored in a computer-readable medium, such as a non-transitory computer-readable medium. The steps in the method of FIG. **2**A might not all be performed in the order specified and some steps may be omitted or changed in order.

At step **131**, a map and/or GPS coordinates may be received. For example, the map and/or GPS coordinates may be loaded from memory. The map and/or GPS coordinates may have been measured when scanning PV modules. The received map may comprise a non-identifying map (NIM), which might not include identifying module information.

At step **132**, the GPS measurements may be grouped into rows. In some embodiments, the grouping into rows may be done while scanning one or more modules. For example, a scanning operator may press a reset button when beginning to scan, or prior to scanning, each row. In some embodiments, the grouping of measurements into rows may be carried out by a computer algorithm, using methods further described herein. The grouping of measurements into rows may be helpful, for example, when the PIM is generated using an NIM, which already indicates the number of rows and the length of each row. In embodiments in which the PIM is generated without benefit of a pre-existing NIM, the grouping into rows may allow for filtering of measurement noise. For example, filtering, or reduction, of measurement noise may be performed by determining the standard distance and angle between adjacent panels in a same row. Steps **133-37** may be performed iteratively, until the first row of scanned samples has been considered as a candidate to represent each row of the installation. At step **133**, a row is selected from the NIM. At step **134**, the first row of location measurements may be fit to the selected row. At step **135**, having fit the first row of location measurements to the selected row, the other rows of measured samples may be fit to the other rows of the NIM, using "snap to grid" or similar methods. In some embodiments, attempted fitting of the other rows of measured samples to the other NIM rows may be carried out multiple times, using multiple row orientations, before an optimal fitting (by an appropriate criterion such as Least Squares) is selected.

At step **136**, a total fitting error may be calculated. The total fitting error may be based on the estimated locations of each device and/or the locations indicated by the NIM. Estimated individual errors of each device may be aggregated by an appropriate criterion, such as Sum of Squares. The selected fitting and resultant aggregated error may be stored. For example, the selected fitting and resultant aggregated error may be stored in an appropriate memory device.

At step **137**, the method may determine if all NIM rows have been considered as the row represented by the first row of measurements. If some NIM rows have not been considered the method may loop back to step **134**. For example, the NIM rows that have not been considered may be candidates for consideration in later iterations. If it is determined, at step **137**, that all NIM rows have been considered, the method may proceed to step **138**.

At step **138**, one or more aggregated errors calculated and stored at step **136** may be compared to one another to select a fitting. In one implementation, a fitting corresponding to the minimum aggregated error may be selected. Other factors may be considered at step **138**.

At step **139**, the fitting selected at step **138** may be output, transforming the NIM to a PIM that includes the fitting selected at step **138**. In some embodiments, steps **134-37** may be modified such that instead of fitting the first row of measurements to each row in the NIM, each row of measurements is fitted to a certain row of the MM (for example, the first row of the NIM).

Reference is now made to FIGS. **2**B and **2**C, which depict illustrative examples of a PV installation which may be mapped according to illustrative embodiments. FIG. **2**B illustrates a Non-Identifying Map (NIM) **215** that may be generated, using methods described herein, to reflect a layout of the PV installation. FIG. **2**C illustrates an Estimated Layout Map (ELM) **217** of the installation, which may be obtained using methods described herein to estimate the absolute locations of PV devices or the locations with regard to one another. FIGS. **2**B and **2**C may correspond to a same PV installation.

In FIGS. **2**B-D, the illustrated squares may correspond to device locations according to the NIM, and the circles may correspond to device locations according to measured data corresponding to the devices. In certain instances, the PV system may be of a non-symmetric layout. For example, in the NIM **215**, one row has two fewer devices than the other two rows. In certain instances, because of measurement inaccuracies and/or noise, an ELM, such as the ELM **217**, may contain inaccuracies.

Reference is now made to FIG. **2**D, which illustrates aspects of steps **134-36**, described above in FIG. **2**A, as applied to the PV system illustrated in FIGS. **2**B-C. In Fitting A, at step **133**, the first row of the NIM is selected. At step **134**, the first row of location measurements is fit to the selected first row of the NIM, and at step **135** the remaining two rows are fit to the NIM in a way that minimizes the total mismatch between the NIM-devices (depicted as squares) and the ELM devices (depicted as circles). At step **136**, the total fitting error is calculated. Different error measures may be considered. For example, a sum-of-squares error measure may be considered. If, for example three devices are estimated to be at the following locations along the XY-plane: (0,0), (1,0) and (2,0), while according to the NIM the three devices are actually located at (0,0.5), (1, 1.5) and (2,0), the square of the estimation error for the first device will be $(0-0)^2+(0-0.5)^2=0.25$. Similarly, the squared estimation error for the second device will be $(1-1)^2$ $(0-1.5)^2=2{,}25$. The third device location is perfectly estimated, with zero error, leading to a total error of 2.5. Other error measures may be considered as well, such as Sum of Absolute Errors, or weighted variations which may take other considerations into account and/or add penalty factors to certain types of errors.

At step **137**, the method may loop back to step **133**, as the first row of measurements has been fit to the first NIM, and other map rows have not been fit. At step **134**, the first row of measurements is fit to the second NIM row, and at step **135**, the other EL rows are "snapped" to the NIM and fitted to the other NIM rows, as shown in Fitting B. The matching illustrated in Fitting B is less successful than the one shown in Fitting A, and the fitting error calculated in step **136** will be higher. At step **137**, the method will determine that the first row of measurements has not yet been fit to one of the NIM rows (the third), and it will loop back to step **133** and select the third NIM row. At step **134**, the first row of measurements may be fit to the third NIM row, and at step **135**, the other EL rows may be "snapped" to the NIM and fitted to the other NIM rows. Several fittings are possible, as illustrated by Fitting C and Fitting D, and by various methods the algorithm can be configured to consider multiple fittings and select one of the fittings, for example, a fitting with minimal estimation error or a least estimation error. At step **136** the fitting error will be calculated, and at step **137** the algorithm will determine that the first row of measurements has now been fit to all of the NIM rows, and will proceed to step **138**. At step **138**, the algorithm will determine that Fitting A has the lowest estimation error of all the fittings considered, and will output Fitting A at step **139**.

FIG. **3**A is a flow diagram of a method for generating an installation map based on time and location according to one or more illustrative aspects of the disclosure. In one or more embodiments, the method of FIG. **3**A, or one or more steps thereof, may be performed by one or more computing devices or entities. For example, portions of the method of FIG. **3**A may be performed by components of a computer system. The method of FIG. **3**A, or one or more steps thereof, may be embodied in computer-executable instructions that are stored in a computer-readable medium, such as a non-transitory computer-readable medium. The steps in the method of FIG. **3**A might not all be performed in the order specified and some steps may be omitted or changed in order.

The method of FIG. **3**A may be used for grouping device measurements into rows. For example, the method of FIG. **3**A may be performed at step **132** of FIG. **2**A. According to this illustrative embodiment, each row of an installation may be processed such that the time that elapses between scanning a device in the row and the adjacent device in the row is less than a certain threshold, such as, for example, 10 seconds. The installer may be instructed to scan each device in the row rapidly, and take a short break between rows. The scanning device may be configured to record the time each device was scanned.

At step **310**, a time difference between each pair of consecutive scans may be calculated. At step **320** the calculated time differences may be compared to a threshold amount of time. In some embodiments the threshold may be preset or predefined, and in some embodiments the threshold may be derived from calculated time differences (e.g., the threshold may be twenty percent longer than an average time difference between consecutive scans). At step **330**, if the time difference between the timestamps of scanning two consecutive devices is above the threshold, the two devices may be determined to be in different rows, and may be mapped to different rows at step **340**. If the time difference is below the threshold, the two devices may be determined to be in a same row, and mapped to the same row at step **350**. Alternatively, or in addition to the method described above, the installer may be instructed to press a "New Row" button on his or her device between rows, which may indicate completing the scanning of one row and beginning another. The "New Row" button may be used to override timing considerations, and/or to compensate for inconsistent scanning speed.

FIG. **3**B is a flow diagram of a method for mapping samples to strings according to one or more illustrative aspects of the disclosure. In one or more embodiments, the method of FIG. **3**B, or one or more steps thereof, may be performed by one or more computing devices or entities. For example, portions of the method of FIG. **3**B may be performed by components of a computer system. The method of FIG. **3**B, or one or more steps thereof, may be embodied in computer-executable instructions that are stored in a computer-readable medium, such as a non-transitory computer-readable medium. The steps in the method of FIG. **3**B might not all be performed in the order specified and some steps may be omitted or changed in order.

Reference is now made to FIG. **3**B, which shows an illustrative implementation for grouping device measurements into rows. For example, the steps described in FIG. **3**B may be performed at step **132**, described above in FIG. **2**A. According to this illustrative embodiment, each row of the installation may be processed such that the distance and/or angle between scanned devices may be compared to a reference distance and/or angle. The scanning device may be configured to determine and/or estimate a global position at the time of each scan, by utilizing localization systems such as Global Positioning System (GPS). At step **315**, the estimated distance and/or angle between each pair of scanned devices may be calculated. At step **325**, the estimated distance and/or angle between scanned devices may be compared to a reference and/or a threshold. In some embodiments the reference may be predefined, while in other embodiments the reference may be derived from calculated distances (e.g., the reference may be the average distance between consecutive scans, with a threshold twenty percent longer than the reference, or the reference may be derived from the angles between consecutive scans, with an appropriate threshold).

At step **335**, the distance and/or angle between two devices, which may have been scanned consecutively, are compared to the reference distance and/or angle. If, at step **335**, it is determined that the distance and/or angle are above the threshold, the two devices may be mapped to different rows, or strings, at step **345**. If, at step **335**, it is determined that the distance and/or angle are below the threshold, the two devices may be mapped to a same row, or string, at step **355**. Alternatively, or in addition to the method described above, the installer may be instructed to press a "New Row" button on his or her device between rows, which may indicate him or her completing the scanning of one row and beginning another. The "New Row" button may be used to override distance and/or angle considerations, and/or to compensate for inconsistent distances and/or angles between devices in the same row.

Reference is now made to FIG. **4**, which depicts one illustrative embodiment of representing a Non-Identifying Map (NIM). Generation of a representation of an NIM may be included in installation mapping methods including steps such as step **100** from FIG. **1**, which is described above. A PV installation may be represented as a text file which contains information regarding the installation. For example, an NIM may be represented by a text file which lists the rows in the installation, the number of devices in each row, and/or the distance between each pair of devices. Additional information such as absolute locations of some devices, row orientation, angles and distances between rows, or other information may be included in the NIM. The mapping method may include an appropriate parser to parse the text file and extract information from the NIM to compare the scanned information to the NIM layout.

FIG. **5**A is a flow-chart of generating a Non-Identifying Map. In one or more embodiments, the method of FIG. **5**A, or one or more steps thereof, may be performed by one or more computing devices or entities. For example, portions of the method of FIG. **5**A may be performed by components of a computer system. The method of FIG. **5**A, or one or more steps thereof, may be embodied in computer-executable instructions that are stored in a computer-readable medium, such as a non-transitory computer-readable medium. The steps in the method of FIG. **5** might not all be performed in the order specified and some steps may be omitted or changed in order.

FIG. **5**A, depicts an illustrative embodiment of generation and representation of a Non-Identifying Map (NIM). For example, the steps described in FIG. **5**A may be performed during the method described in FIG. **1**. A program or application may be used to design and plan a PV installation. The program may run on appropriate platforms (PCs, tablets, smartphones, servers, etc.), and may be made available to installers and/or system designers. The program may include a Graphic User interface (GUI) to facilitate in site planning. At step **101**, the site planner or designer may use the program or application to design a PV installation using the tools made available by the application. For example, FIG. **5**B illustrates an example of a user interface for PV installation mapping that may be used at step **101** of FIG. **5**A to design the PV installation. A user may design a PV installation featuring a plurality of photovoltaic generators **501** (e.g. PV panels, PV modules, PV cells, strings or substrings of PV panels) and featuring one or more power converters (e.g. PV inverter **502**).

At step **102**, of FIG. **5**A, a binary file may be generated comprising information describing a portion of or the full layout of the system. The binary file may be generated at step **102** after a layout of the PV installation has been designed using the program GUI. Embodiments of the PV installation mapping methods described herein may include a step **103** of reading the binary file generated at step **102** and extracting site layout information from the binary file.

Reference is now made to FIG. **6**, which shows components for scanning a PV device and logging the time and/or location of the scanner at the time of scanning. PV device **602** (e.g. PV panel, optimization device, DC/DC converter, inverter, monitoring device, communication device, etc.) may be marked with an ID marker **600** that can be scanned or processed, ID marker **600** may be a barcode that can be scanned by a scanning device. ID marker **600** may be a serial number identifiable by a camera, such as a camera with digit-identification capabilities. ID marker **600** may be an RFID tag, or a memory device readable by an electronic circuit. It should be understood that any other type of marker may be used in addition to or instead of the listed examples.

Scanning and localization device **601** may capture or record data provided by the ID marker **600**. For example, the device **601** may be configured to obtain the identifying information from PV device **602**, by scanning, taking a picture of, or retrieving data stored by the ID marker **600**. Device **601** may include a clock and memory device, and be configured to store the timestamp of each scan along with the identifying information of the device scanned at that time. Device **601** may include a localization device such as a GPS device, configured to communicate with satellites **603** and estimate the location of the device at the time of scanning. In one implementation, the GPS methods employed may allow for estimates with sufficient accuracy to provide differentiation between adjacent PV devices deployed in the same installation.

Reference is now made to FIG. **7**, which shows examples of scanning and locating devices that can be used in conjunction with illustrative embodiments described herein. Combined device **700** may include one or more of the illustrated components. ID reader **203** may be configured to retrieve identifying information from a PV device. In some embodiments, ID reader **203** may comprise a camera, and may be configured to take a photograph of a serial number or other identifying information on the PV device. In some embodiments, ID reader **203** may comprise a barcode scanner and be configured to scan a barcode on the PV device. In some embodiments, ID reader **203** may comprise an electronic circuit configured to read an RFID tag or a memory device storing identifying information.

In some embodiments, the device **700** may include GPS device **201**, configured to receive or determine a GPS location, for example, when scanning a PV device. The device **700** may write (e.g. record, store, transmit, etc.) the ID information and GPS coordinates to data logging device **202**. The data logging device **202** may comprise flash memory, EEPROM, or other memory devices.

Controller **205** may synchronize the various components comprising device **700**. The controller **205** may comprise a DSP, MCU, ASIC, FPGA, and/or a different control unit. The controller may be split into several control units, each responsible for different components. Device **700** may include communication device **206**. The communication device **206** may be configured to communicate using a wireless technology such as ZigBee, Bluetooth, cellular protocols, and/or other communication protocols. In some embodiments, measurements, timestamps and/or ID information may be transmitted, for example, by the communication device **206**, to a remote server and/or stored to memory at a remote location. Device **700** may include clock **204**, configured to sample, store, and/car communicate the time (in conjunction with the memory device and/or communication devices). For example, the clock **204** may be used to record a timestamp each time the ID reader **203** determines (e.g. obtains, measures, etc.) a device ID.

Device **700** may further include tilt sensor **207**, configured to measure the tilt of the device **700** and store the measurement to memory and/or communicate the measurement. The tilt sensor may be used to measure the tilt of PV devices such as PV panel. Scanning device **700** may also include a compass **208**. The compass **208** may be configured to measure or determine the direction a PV module is facing. For example, the compass **208** may be used to measure a direction of a PV module when a tilt measurement is carried out. Determining the tilt of one or more PV panels and/or the direction that the one or more PV panels face may be useful for various applications, such as monitoring applications or mapping applications. If the tilt of the PV panels is fixed during deployment, the installer may want to measure tilt and angle while scanning the PV devices for mapping purposes. The scanned data may be uploaded to a remote monitoring device.

In some embodiments, a device such as mobile phone/tablet **710** may include some or all of the functionality described with regard to combined device **700**. Combined device **700** may also include a screen, configured to display the information generated by the device. In one implementation, the screen may display information in real-time, which may allow the installer to monitor progress, and may improve scanning accuracy. Many mobile devices include ID readers such as barcode scanners or a camera, a GPS device, controller, communication methods, a clock, compass and tilt sensor. Application software may be downloaded to the mobile device to allow the different components to interact in a way that achieves the desired functions described herein with regard to mapping PV installations. The mobile device may allow the installation map to be displayed on the device's screen while scanning, and show real-time updating of the information attached to each PV device in the field, to aid the installer in determining that the information is being processed accurately and clearly.

FIG. **8**A is a flow diagram of a method for installation mapping according to one or more illustrative aspects of the disclosure. In one or more embodiments, the method of FIG. **8**A, or one or more steps thereof, may be performed by one or more computing devices or entities. For example, portions of the method of FIG. **8**A may be performed by components of a computer system. The method of FIG. **8**A, or one or more steps thereof, may be embodied in computer-executable instructions that are stored in a computer-readable medium, such as a non-transitory computer-readable medium. The steps in the method of FIG. **8**A might not all be performed in the order specified and some steps may be omitted or changed in order.

Reference is now made to FIG. **8**A, which shows an illustrative method for estimating relative positions of a plurality of PV devices with regard to one another. In one implementation, the position may be estimated, or determined, without the use of localization devices, such as satellites. All or a portion of the PV devices in a PV installation may be equipped with a communication device, such as a wireless transceiver running an appropriate wireless protocol (e.g. Bluetooth, ZigBee, Wi-Fi, LTE, GSM, UMTS, CDMA etc.) or a Power-Line Communication (PLC) transceiver, which may be coupled to the PV installation's cables and configured to communicate by sending messages to each other over the cables.

At step **800**, a mapping algorithm may be initialized by assigning random locations to each of the PV devices that are to be mapped. In one implementation, one or more of the devices may begin communicating by broadcasting an ID number, the current timestamp, and/or other information over the communication medium (e.g. power cables, wireless channels). For example, the ID number, timestamp, or other information may be transmitted at a predetermined amplitude. All or a portion of the devices may be able to detect the ID signals that are broadcast by the other devices. The received signal strength and/or the time it takes for the signal to propagate from one device to the next may depend on the distance and signal attenuation between the devices. In some embodiments, the devices may engage in one-way communication only, i.e. each device might only send messages to some or all of the other devices without being configured to receive a response from any particular device(s). In some embodiments, two or more devices may engage in two-way communication (e.g. Device A sends a message to Device B requesting a response, and measures the elapsed time between sending the message and receiving the response).

At step **805**, the signal strength of each signal received by each device and/or the time delay between sending and receiving messages may be measured. At step **810** the signal strength and/or time delay measured at step **805** may be used to generate one or more initial estimates of pairwise distances between devices. The initial estimates may comprise error, such as error due to stochastic attenuation factors, noisy channels, and/or unexpected delays in signal propagation. In one implementation, multiple measurements may be taken and then averaged, or some other function may be applied to the measurements. In this implementation, an initial accuracy of the measurements may be improved by taking multiple measurements.

At step **815**, the initial distance estimates generated at step **810** may be input to an algorithm, which may analyze the initial pairwise distance estimates and use them to generate an Estimated Layout Map (ELM). Many algorithms for this step may be considered, and in some embodiments, combinations of algorithms may offer accurate results. For example, a Least Squares (LS) problem may be formulated to create an ELM which minimizes the disparity between the pairwise estimated distances between various devices. A myriad of other methods, such as simulated annealing, Convex Optimization, Semidefinite Programming, or Multidimensional Scaling can be combined with transliteration and/or triangulation techniques to obtain an estimated layout based on the measurements.

At step **820**, it may be determined whether a non-identifying map (NIM) is available. If a NIM is available, the method may proceed to step **840**. At step **840**, the NIM and ELM may be input to a matching algorithm which may incorporate elements of the method illustrated in FIG. **2**A, and further discussed in FIGS. **2**B-D, to match the identifying information incorporated in the ELM to the device locations described by the NIM. At step **845** the matching algorithm may run, i.e., execute, and at step **850** a map of the installation may be output which outlines the device locations along with ID information for each device. The map may be in a format viewable on an appropriate device, such as a computer monitor, mobile phone, tablet, etc. The map may be represented digitally or in a textual format.

Alternatively, if no NIM is available at step **820**, the algorithm may proceed to step **825**. At step **825** the method may seek "anchor devices", i.e., a set of one or more specific devices which have known locations. If such anchors exist (or can be easily obtained by the installer), certain device IDs from the ELM may be matched to the known locations at step **835**, and the rest of the devices may be arranged around them, with the final arrangement then output at step **850**. If no anchor devices exist or can be obtained, the algorithm may use the current solution without further modification at step **830**, proceed from step to step **850**, and output the ELM "as is", as a final map of the installation with ID information for each device. The method of FIG. **5**A may be carried out by a centralized processing device which has access to the measurements taken by some or all of the PV devices (e.g., a system inverter including a processing unit, communicatively coupled to the PV devices so that the devices can communicate their measurements to the inverter).

Reference is now made to FIG. **8**B, which illustrates different stages of the mapping algorithm depicted in FIG. **8**A according to a certain illustrative embodiment. In this illustrative embodiment, for illustrative purposes, step **815** comprises two stages. The first stage may include utilizing a mesh-relaxation technique, such as described in "Relaxation on a Mesh: a Formalism for Generalized Localization" by A. Howard, M. J. Mataric and G. Sukhatme (*Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems* (*IROS* 2001), with the result of the first stage being formulated as a Least-Squares problem and input to a Least-Squares solving method (many of which can be found online, such as the "leastsq" method packaged in the SciPy library for the Python programming language). **870** depicts the real layout of the PV installation, with each device numbered (0-119) and located in its "real" place. The real layout depicted in **870** is not known to the algorithm at the time of running, and is provided here for illustrative purposes. **880** depicts an example result of step **800**, where the mapping algorithm has generated random location estimates for each device. In this illustrative embodiment, RSSI indicators (in conjunction with estimated random signal attenuation factors) are used to estimate pairwise distances between each pair of devices, and the estimates are input to an implementation of the "Relaxation on a Mesh" method mentioned above, at a first stage of step **815**. The resultant ELM is depicted in **890**, which includes some misaligned rows and a few devices which deviate from their "real" location illustrated in **870**. The estimate depicted in **890** may then be input to the SciPy "leastsq" function, and a final, smooth, accurate ELM may be output, such as the output depicted in **895**. It should be noted that the diamond-like shape of the ELM of **895** is obtained because of unequally scaled X and Y axes. For example, if the axes in L**4** were scaled equally, the shape may be that of a rectangle, which may be similar to the real installation as illustrated in L**1**. In one implementation the ELM **895** illustrates an estimate at the end of step **815**. In the example illustrated in FIG. **8**B, the degree of symmetry present in the installation may reduce accuracy of the estimated layout. In certain instances, a PV installation may include asymmetrical elements (e.g. some rows being shorter than other, such as in the system depicted in FIG. **2**B) which may improve accuracy when matching ELM elements to NIM elements. In certain instances, asymmetrical elements may result in improvements in algorithmic convergence and accuracy.

Reference is now made to FIG. **9**, which shows an illustrative PV installation comprising PV devices which may be described on a map of the installation. The installation may include a plurality of PV strings **916***a*, **916***b*, to **916***n*. The PV strings may be connected in parallel. Each PV string **916***a-n* may include a plurality of PV devices **903**. PV devices **903** may be PV cells or panels, power converters (e.g. DC/DC converters or DC/AC converters) coupled to or embedded on PV panels, monitoring devices, sensors, safety devices (e.g. fuse boxes, RCDs), relays, and the like, or any combinations thereof. Individual PV devices **903** may be identical or might be different. The PV devices **903** may be coupled in series or in parallel. For example, each PV device **903** may comprise a DC/DC converter or DC/AC inverter coupled to a PV panel and configured to operate the panel at a set or determined power point, such as a maximum power point. Each DC/DC or DC/AC converter may convert input PV power to a low-voltage, high-current output, and multiple converters may be serially connected to form a string having high voltage. In some embodiments, each PV device **903** may include DC/DC or DC/AC converter converting input PV power to a high-voltage, low-current output, and multiple converters may be connected in parallel to form a string having high current.

The plurality of PV strings **916***a-n*, which may be connected in parallel, may be coupled to the inputs of PV system grouping device **904**. In some embodiments, PV system grouping device **904** may comprise a central inverter configured to convert a DC input to an AC output. The AC output may be coupled to a power grid. In some embodiments, PV system grouping device **904** may comprise one or more safety, monitoring and/or communication devices. Each of the PV devices **903** and/or the grouping device **904** may include an ID tag such as a barcode, serial number and/or memory or RFID card, that comprises identifying information.

In illustrative embodiments, it may be possible to match device IDs to physical locations on a map by utilizing various methods described herein. In some embodiments, it may be possible to match device IDs to physical locations on a map by determining which devices are coupled serially to one another (i.e. which devices comprise each string), determining the order of the various strings and then determining the order of the devices within each string.

FIG. **10** is a flow diagram of a method for grouping power devices into groups according to one or more illustrative aspects of the disclosure. In one or more embodiments, the method of FIG. **10**, or one or more steps thereof, may be performed by one or more computing devices or entities. For example, portions of the method of FIG. **10** may be performed by components of a computer system. The method of FIG. **10**, or one or more steps thereof, may be embodied in computer-executable instructions that are stored in a computer-readable medium, such as a non-transitory computer-readable medium. The steps in the method of FIG. **10** might not all be performed in the order specified and some steps may be omitted or changed in order.

Reference is now made to FIG. **10**, which depicts a method for grouping PV devices into strings. The method may be used to determine which devices are serially connected to one another in systems such as the system depicted in FIG. **9**. The method of FIG. **10**, or one or more steps thereof, may be used to group devices into map rows, such as at step **132** of FIG. **2**A. The method may apply to a plurality of PV devices which are able to change their output voltage, such as DC/DC converters, and report their output parameters (e.g. voltage, current) to a system management unit communicatively coupled to some or all the PV devices.

At step **900**, it may be determined that one or more power devices are ungrouped. For example, initially, all power devices may be ungrouped. At step **910**, a power device may be selected from the ungrouped power devices. The power device may be selected randomly. For example, an optimizer, such as an optimizer coupled to a power generation source, may be selected. In one implementation, all or portions of step **910** may be performed by an inverter. At step **920**, the power device selected at **910** may be instructed to decrease or increase an output voltage of the power device. For example, a message may be sent to the power device, via PLC, wirelessly, or via other communications methods, to increase or decrease the output voltage of the power device.

At step **930**, the method may wait for power devices, such as ungrouped power devices, to report operating points. For example, the power devices may send telemetries based on a schedule or at various intervals. At step **940**, operating points received from power devices, such as ungrouped power devices may be recorded. The operating points may be responsive to the increase or decrease in output voltage that was requested at step **920**.

At step **950**, one or more devices that do not report a change in voltage may be grouped with the power device selected at step **910**. For example, devices that do not report a change in voltage greater than a threshold change in voltage may be grouped with the selected power device. The threshold may be preset or predetermined, or determined based on received operating points.

At step **960**, it may be determined whether there are one or more ungrouped devices. If there are one or more ungrouped devices, the method may return to step **910** and select one of the one or more ungrouped devices. Otherwise, if at step **960** it is determined that all devices have been grouped, the method may proceed to step **970**. At step **970**, the grouping may be considered complete, and the division of devices into groups may be output.

As an example of the method described in FIG. **10**, assume PV system grouping device **904** is an inverter including a power-line-communications (PLC) or wireless transceiver and a processor, and each PV device is an optimizer including a DC/DC converter, a maximum-power-point-tracking (MPPT) circuit and a PLC or wireless transceiver. Each optimizer may be coupled to one or more power generation sources such as PV panels, batteries and/or wind turbines. Before the grouping process begins, each optimizer may be configured to output a certain low, safe voltage such as 1V. Since the strings of optimizers (e.g. **316***a*, **316***b*) are coupled in parallel, they will maintain a common voltage between the two ends of each string. The optimizers may periodically send telemetries to the PV system grouping device **904** using PLC, where they report their current output voltages. At step **900**, the power devices (optimizers in this example) are ungrouped. At step **910**, the inverter chooses a first optimizer at random (e.g. Optimizer A, belonging to String F), and at step **920** sends a message (via PLC or wirelessly) instructing Optimizer A to increase its output DC voltage. This increase in voltage results in a corresponding increase in the voltage of the string including the chosen optimizer, String F. To maintain a common string voltage, the optimizers belonging to all the other strings may increase their voltages as well. However, the optimizers which are part of String F (e.g. Optimizers B-K) might not increase their output voltage, as Optimizer A has already raised its voltage. When the optimizers next send telemetries to the inverter, via PLC or wirelessly, at step **930**, Optimizer A will report a high voltage, Optimizers B-K will report the same voltage as before, and all other optimizers will report increases in voltage. At step **940**, the inverter processor will record the reports from all the optimizers. At step **950**, the inverter will determine that all optimizers not reporting a significant change in voltage (B-K) belong to the same string as the originally selected optimizer (A), group them as a string and remove them from the "ungrouped power devices pool". The algorithm then repeats steps **910-50** until all optimizers have been grouped, at which stage it comes to an end, at step **970** outputting the division of optimizers into groups.

Reference is now made to FIG. **11**A, which shows an illustrative embodiment of a PV string of PV devices, where it may be possible to determine the order of the devices within the string. Time Domain Reflectometry (TDR) may be used to determine the ordering of PV devices within a PV string. String **317** may comprise a plurality of serially-connected PV devices **104**, such as PV devices **104***a*, **104***b*, to **104***k*. The string **317** may comprise any number of PV devices **104***a-k*. Devices **104***a-k* may comprise elements similar to those previously discussed with regard to PV devices **903**. Devices **104***a-k* may each include power converter **210** (e.g. a DC/DC or DC/AC converter) which receives input from a PV panel, battery or other form of energy generation, and produces an output. One output of converter **210** may be coupled to a variable impedance Z, and the other output may serve as the device output, to be coupled to an adjacent PV device in string **317**. In this manner, string **317** may include a plurality of variable impedances which are coupled to the cables which couple the PV devices to one another, forming the serial string. Each PV device **104***a-k* may include a controller **220**, configured to control the value of variable impedance Z. Controller **220** may be the same controller used to control the other components of PV device **104***a-k* (e.g. power converter **210**, communication module **230**, safety device(s) **240**, auxiliary power **250**, etc.), or it may be a different controller. Transceiver **115** may be coupled to the string **317**, and may be configured to inject a voltage or current pulse over the string and measure the reflected wave. The transceiver may be coupled to one of the edges of the string, or may be coupled to a middle point between two devices. According to TDR theory, the waveform reflected back to the transceiver depends on the characteristic impedance of the PV string line. The characteristic impedance of the PV string may be affected by each of the variable impedances coupled to it, so by rapidly changing the variable impedance on one of the serially connected PV devices, a rapidly changing reflected waveform may be formed.

Reference is now made to FIG. **11**B, which shows several examples of variable impedance configurations. Variable impedance **1110** may include inductor L**1**, resistor R**1**, capacitor C**1** and switch Q**1** (e.g. a MOSFET), all connected in parallel. When switch Q**1** is ON (e.g. by a controller applying an appropriate voltage to the gate of MOSFET) the total impedance of impedance **1110** may be zero, since the switch bypasses the other impedance elements. When switch Q**1** is off, the impedance of **1110** may be nonzero, and may be calculated as the impedance of the other three components connected in parallel. Variable impedance **1120** may comprise inductor L**2**, resistor R**2**, capacitor C**2** connected in parallel, inductor L**22** coupled to them in series, and switch Q**2** connected in parallel to the whole arrangement. Here, when Q**2** is ON the equivalent impedance of **1120** may be zero, and when it is OFF the impedance of **1120** may be nonzero, and calculated as the impedance of R**2**, C**2** and L**2** in parallel added to the impedance of L**22**. Variable impedance **1130** features two switches, Q**3** and Q**33**, and more than two impedance levels. When Q**3** is ON, the impedance of **1130** is zero. When Q**3** and Q**33** are both OFF, the impedance of **1130** is simply the impedance of inductor L**3**. When Q**3** is OFF and Q**33** is ON, the impedance of **1130** is the equivalent impedance of inductor L**3**, resistor R**3** and capacitor C**3** all coupled in parallel. Obviously, many more arrangements of components may be utilized for different (or additional) impedance levels. The switching of the switches (Q**1**, Q**2**, Q**3**, Q**33**) may be controlled by an appropriate controller (e.g. DSP, MCU, FPGA etc.) within the relevant PV device.

Reference is now made to FIG. **12**, which shows a waveform reflected from a PV string including variable impedances, according to illustrative embodiments described herein. If illustrative variable impedances are switched at a very high frequency (e.g. a frequency above 100 kHz, such as hundreds of kilohertz, several megahertz, tens or hundreds of megahertz, or several gigahertz), a ripple may be detected on the wave reflected back to the transceiver. If several variable impedances are varied on the same string, the ripple each impedance causes may appear at a different time, due to the difference in distance between impedances. For example, if two PV devices including variable loads are spaced 1.5 meters apart, with one of the PV devices being 1.5 meters closer to the transceiver than the other, the waveform transmitted by the transceiver will travel an additional 1.5 meters to reach the further PV device, and the reflected wave will travel an additional 1.5 meters as well on the way back, for a total difference of 3 meters in the route. Assuming the waveforms travel at the speed of light, $C=3\cdot 10^8$ m/sec, the ripple caused by the farther variable impedance will appear

$$\Delta t = \frac{3[\mathrm{m}]}{3\cdot 10^8\left[\frac{\mathrm{m}}{\mathrm{sec}}\right]} = 10[\mathrm{ns}]$$

later than the ripple caused by the closer variable impedance. High-quality digital or analog sensors may be able to detect time differences at this resolution. For example, if transceiver **115** commands device **104***b* to vary its impedance, it may detect a ripple appearing on the reflected waveform after 200 [ns]. If transceiver **115** commands device **104***a* to vary its impedance, and it detects a ripple appearing on the reflecting waveform after 210 [ns], it may determine that device **104***a* is 1.5 [m] further than device **104***b*. By iteratively sending similar commands to each device in the system, the transceiver unit may be able to determine the relative distances of each PV device, and in conjunction with grouping the devices into strings and/or rows (using methods such as the illustrative embodiments shown in FIG. **10**), the location of each device may be determined.

FIG. **13** is a flow diagram of a method for testing power devices according to one or more illustrative aspects of the disclosure. In one or more embodiments, the method of FIG. **13**, or one or more steps thereof, may be performed by one or more computing devices or entities. For example, portions of the method of FIG. **13** may be performed by components of a computer system. The method of FIG. **13**, or one or more steps thereof, may be embodied in computer-executable instructions that are stored in a computer-readable medium, such as a non-transitory computer-readable medium. The steps in the method of FIG. **13** might not all be performed in the order specified and some steps may be omitted or changed in order.

Reference is now made to FIG. **13**, which described an illustrative method which may be used to determine the relative distances of serially connected PV devices from a waveform-generating transceiver, in a system which may be arranged similarly to the system shown in FIG. **11**A. At step **1320**, one or more power devices may be defined as "untested", i.e., they have not been commanded to vary their impedance. For example, initially, all power devices may be determined to be untested.

At step **1325**, one of the untested devices is selected. For example, an untested device may be selected randomly at step **1325**. At step **1330**, the device selected at step **1325** may be commanded to vary its variable impedance. For example, the device may be commanded to vary its variable impedance at a determined frequency, such as a high frequency. At step **1335**, a transceiver may transmit a voltage pulse over the PV string. At step **1340**, the transceiver may receive the reflected wave, record and/or time the response, and save the received or determined data to memory at step **1345**. At step **1350**, the selected device may be removed from the pool of "untested" devices, and may be commanded, for example, by the transceiver, to stop varying its output. At step **1355**, the transceiver may check or determine if there are devices in the string which are untested. If there are untested devices, the method may return to step **1325**, and another power device may be selected. If it is determined, at step **1355**, that all power devices have been tested, the method may proceed to step **1360**. At step **1360** the transceiver (or a master control unit or other system which receives data from the transceiver) may analyze the saved reflected waveforms and time samples, determine (as explained previously) which devices are closer than others, and estimate the distances between devices.

Reference is now made to FIG. **14**, which shows an illustrative PV arrangement. In PV arrangement **309**, PV devices **105***a*, **105***b*, to **105***k* are coupled in parallel to one another. Although not illustrated in FIG. **14**, the devices **105***a-k* may be coupled in parallel to a system power device such as an inverter, management and/or communication unit, safety device(s), or other devices. Each PV device **105***a-k* may be coupled to a power source (e.g. PV panel, battery, wind turbine etc.) and may include a DC/DC or DC/AC converter configured to output a high-voltage DC or AC voltage which is common to all PV devices **105***a-k* coupled in parallel. In this illustrative system, devices **105***a-k* might not be coupled in series with one another. Transceiver **116** may be coupled to the PV devices **105***a-k* and may be configured to communicate with the devices **105***a-k*. It may be desirable for the system installer to know the distances between the various devices and the transceiver, or to know the distance ordering (i.e. which device **105***a-k* is closest, which is the farthest, etc.). In parallel-connected embodiments, a voltage or current pulse may be transmitted, with the PV devices **105***a-k* taking turns varying their impedance as instructed by the transceiver **116**, as explained above in regards to FIGS. **11**A-**14**. In this embodiment, the transceiver **116** may analyze the current returning wave for disturbances caused by the varying impedance circuits, and based on the time delay in recording caused by each PV device, determine and/or list the devices **105***a-k* in order of distance from the transceiver **116**.

Reference is now made to FIG. **15**A, which depicts a PV device according to illustrative embodiments. PV panel **106** may include one or more solar cells on one side (not explicitly shown), and a lower portion of a junction box **152** on a second side. A plurality of panel conductors **153** such as ribbon wires may be coupled to the PV cells on one side of the panel, and may protrude through slots in the lower junction box portion **152** on the other side. The lower junction box portion **152** may be fastened to the PV panel **106** at the time of manufacturing. An identification label (ID label) **151** may be attached to the panel **106** or lower junction box portion **152** either at the time of manufacturing or thereafter. The ID label **151** may be a barcode, serial number, RFID tag, memory device or any other medium for containing information that can be read by an external device. An upper junction box portion **150** may be mechanically attachable to the lower junction box portion, and may include electronic circuits configured to receive PV power from the conductors **153**, and may include string conductors **154** for coupling the upper portion to adjacent PV devices. In some embodiments, the upper junction box portion **150** may be coupled to other upper box portions at the time of manufacturing, using conductors of appropriate length to allow a plurality of upper portions **150** to be attached to a plurality of lower junction box portions during deployment in a PV installation. The upper junction box portion **150** may include an appropriate device for reading the ID label **151** from the panel or lower junction box portion. For example, if the ID label **151** includes a barcode, the upper portion **150** may include a barcode scanner. If the ID label **151** includes a serial number, the upper portion **150** may include a camera and be coupled to a device configured to identify digits and/or letters. The upper portion **150** may include an RFID tag reader, or a device configured to read identifying information from a memory device. The upper portion **150** may read, process and/or communicate the ID information automatically when attached to the lower junction box portion **152**. The upper junction box portion **150** may also be configured with its own ID information, and be able to communicate to a management device both its own ID tag and the ID label of the PV panel it is coupled to.

PV device ID tags may be used for several purposes. In some embodiments, the ID tags may be used to create a map of the PV installation including the locations of specific devices in the installation. In some embodiments, the tags may be used to authenticate PV devices and ensure that approved devices are used in the installation, for example, by using an authentication protocol. In some embodiments, the protocol may be carried out by circuits and/or devices comprised in the upper part of the junction box. In some embodiments, the ID tag may be communicated to an external management device, and an authentication protocol may be carried out between components included in the lower portion, the upper portion and an external device or management unit.

Reference is now made to FIG. **15**B, which shows an illustrative embodiment of an upper portion of a junction box, such as the one that may be used in the arrangement depicted in FIG. **15**A. Upper junction box portion **150** may comprise power converter **245**, which may be configured to receive DC power from a PV panel and convert it to DC or AC power at the converter outputs. Upper junction box portion **150** may comprise variable load **275**. Upper junction box portion **150** may comprise an ID reader **285**. Upper junction box portion **150** may further comprise controller **270** such as a microprocessor, Digital Signal Processor (DSP) and/or an FPGA, configured to control some or all of the other functional blocks. In some embodiments, the controller may be split into multiple control units, each configured to control one or more of the functional blocks of upper portion **150**. Upper junction box portion **150** may comprise Maximum Power Point Tracking (MPPT) circuit **295**, which may be configured to extract power, such as a maximized power, from the PV module the upper portion **150** is coupled to. In some embodiments, controller **270** may include MPPT functionality, and thus MPPT circuit **295** may not be included in the upper portion **150**. Controller **270** may control and/or communicate with other elements over common bus **290**. In some embodiments, the upper junction box portion may include circuitry and/or sensors **280** configured to measure parameters on or near a PV module or junction box, such as voltage, current, power, irradiance and/or temperature. In some embodiments, the upper junction box may include communication device **255**, configured to transmit and/or receive data and/or commands from other devices. Communication device **255** may communicate using Power Line Communication (PLC) technology, or wireless technologies such as ZigBee, Wi-Fi, Bluetooth, cellular communication or other wireless methods. In some embodiments, the upper junction box portion may include safety devices **260** (e.g. fuses, circuit breakers and Residual Current Detectors). The various components included in upper junction box portion **150** may communicate and/or share data over common bus **290**.

FIG. **16** is a flow diagram of a method for grouping power devices into strings. The method may be used to determine which devices are serially connected to one another in systems such as the system depicted in FIG. **9**. The method of FIG. **16**, or one or more steps thereof, may be used to group devices into map rows, such as at step **132** of FIG. **2**A. The method may apply to a plurality of power devices which are able to report their output parameters (e.g. voltage, current) to a system management unit communicatively coupled to some or all of the power devices. According to Kirchhoff's Current Law (KCL), serially coupled devices carry the same current. According to KCL, if a plurality of serially-coupled power devices repeatedly report their output current to a system management unit at substantially simultaneous times, the reported currents may be substantially the same in magnitude. By logging the reported currents over a period of time, it may be determined which power devices are unlikely to be serially coupled to one another (e.g. if two devices report currents which are significantly different at substantially the same time, they are likely not serially coupled) and by a process of elimination and application of an appropriate stopping condition, an accurate estimate of the arrangement of power devices in a PV system may be obtained.

At step **160**, initial grouping possibilities may be considered. For example, each power device may be considered to be "possibly paired" to each other power device in the system. In some embodiments, more limiting initial possibilities may be considered based on prior knowledge. For example, it may be known that two power devices are not serially coupled to one another, and they may be initially considered "not paired." In some embodiments, a counter may be optionally set to track the number of iterations the method has run. At step **161**, the method may receive current measurements from two or more power devices at substantially the same time.

At step **162**, some of the current measurements may be compared to one another. For example, if Device A and Device B are considered "possibly paired" at step **162** of the method, the current measurements of Device A and Device B, I_A and I_B, respectively, may be compared to each other. If the current measurements are not substantially the same, the estimated relationship between Device A and Device B may be changed to "not paired." In some embodiments, more than one instance of substantially different currents may be required to change an estimated relationship to "not paired." For example, Device A and Device B may be considered "possibly paired" until three pairs of substantially different current measurements have been reported. In some embodiments, the determination of whether currents are substantially the same is based on an absolute current difference. For example, if $|I_A-I_B|\epsilon$ for an appropriate ϵ (e.g. 10 mA, or 100 mA, or 1 A), then I_A and I_B might be considered "substantially the same." In some embodiments, the determination of whether currents are substantially the same is based on a relative current difference. For example, if

$$\frac{|I_A - I_B|}{I_B} < \alpha \text{ and } \frac{|I_A - I_B|}{I_A} < \alpha$$

for an appropriate α (e.g. 0.01, or 0.03, or 0.1) then I_A and I_B might be considered substantially the same. In some embodiments, multiple criteria may be used to determine if two currents are substantially the same.

By comparing pairs of current measurements to each other as detailed above, it may be determined which devices are unlikely to be serially coupled to one another. In some embodiments, the method may compare current measurements of each pair of power devices considered "possibly paired," and based on the result of the comparison, the method may change the relationship between the pair of power devices to "not paired." In some embodiments, the method may compare only a portion of the current measurements to one another. In some embodiments, some or all the current measurements selected for comparison may be chosen at random.

At step **163**, the method determines if a stop condition has been reached. In some embodiments, a stop condition may be reached when a certain number of iterations have been completed. The number of iterations which trigger the stop condition may be fixed (e.g. 10, 50, or 100), or may depend on the number of power devices in the system (e.g. N/10, N/2 or $\sqrt{N}$ for a system containing N power devices). In some embodiments, the stop condition may be triggered when a certain number of iterations have not changed the relationship between any two power devices. For example, if three method iterations have not changed the relationship between any two devices to "not paired," the stop condition may be reached. In some embodiments, the stop condition may be reached when each power device is considered "possibly paired" to no more than a certain number of other devices. For example, a stop condition may be reached if each power device is considered "possibly paired" to no more than twenty devices, or forty devices, or sixty devices. In some embodiments, a stop condition is reached based on a combination of criteria. For example, a stop condition may be reached only if three method iterations have not changed the relationship between any two devices to "not paired," and additionally, each power device is considered "possibly paired" to no more than fifty devices.

If the method determines that the stop condition has not been reached, at step **165** the iteration counter may be incremented, and the method may return to step **161**. If the method determines that the stop condition has been reached, the method may continue to step **164**, and for each Power Device X, output the group of power devices that are considered "possibly paired" to Power Device X (i.e. the "potential group" of Power Device X).

Reference is now made to FIG. **17**A, which shows an illustrative embodiment of a PV string of PV devices, where it may be possible to determine the order of the devices within the string. Selective coupling of PV devices to a common ground may result in leakage current, which may be used to determine the ordering of PV devices within a PV string. String **318** may comprise a plurality of serially-connected PV devices **107**, such as PV devices **107***a*, **107***b*, to **107***k*. The string **318** may comprise any number of PV devices **107***a-k*. The string may be coupled between a ground terminal and a power bus. The voltage between the terminals of each PV device may vary from device to device. For example, in the illustrative embodiment depicted in FIG. **17**A, PV device **107***a* outputs 25V, PV device **107***b* outputs 30V (55V−25V=30V), and PV device **107***k* outputs 39.3V (700−660.7V=39.3V). The string voltage may be the sum of the voltages output by each PV device in the string, with the power bus being at voltage approximately equal to the string voltage.

Devices **107***a-k* may comprise elements similar to those previously discussed with regard to PV devices **903** and/or **104**. Some elements have not been explicitly illustrated. Devices **107***a-k* may each include power converter **211** (e.g. a DC/DC or DC/AC converter) which receives input from a PV panel, battery or other form of energy generation, and produces an output. The converter may include two output terminals for serial coupling to adjacent PV devices in string **318**. One output of converter **211** may further be coupled to a leakage circuit **108** at leakage terminal LT. Leakage circuit

108 may be variously configured. In an illustrative embodiment such as shown in FIG. **17**A, leakage circuit **108** may comprise a serial branch including resistor R, switch Q and current-sensor A**1**. The serial branch may be coupled to a common electrical ground. In some PV installations, the mounting structures used to support PV panels may be required to be coupled to a common ground, and in such embodiments, the leakage branch may be coupled to the ground via the mounting structures. In some embodiments, alternative grounding points may be considered. Resistor R may be of large resistance, such as 10 kΩ, 100 kΩ or even 1MΩ or larger. Switch Q may be implemented using an appropriate device such as a MOSFET. During regular operating conditions, switch Q may be in the OFF position, disconnecting leakage terminal LT from the grounding point. Switch Q may be temporarily be switched to ON, allowing current to flow from the leakage terminal LT to the ground. In some embodiments, where switch Q and current sensor A**1** may have negligible resistance, a current of magnitude approximately proportional to the voltage at leakage terminal LT may flow through the leakage circuit and be sensed by current sensor A**1**. For example, if the voltage at leakage terminal LT is 100V, and the resistor R is of resistance 100 kΩ, current sensor A**1** will sense a leakage current of

$$\frac{100\text{ V}}{100\text{ k}\Omega} = 1\text{ mA}.$$

In some embodiments, PV device **107** may include a communication device for transmitting leakage current measurements to a management device configured to use the current measurements for appropriate calculations (not illustrated explicitly). Controller **214** may be similar to controller **220** described with regard to FIG. **11**A, and may further be configured to control the switching of switch Q. In some embodiments, a separate controller may be dedicated to switching switch Q. Communication device **212** may be configured to communicate with other system power devices for sending or receiving commands or data. For example, communication device **212** may be configured to provide measurements of a voltage or current at leakage terminal LT. Communication device **212** may be a wireless (e.g. a cellular, ZigBee™, WiFi™, Bluetooth™ or other wireless protocol) transceiver, or a wired communication device (for example, a device using Power Line Communications).

Returning to string **318**, in some embodiments each PV device **107** may comprise a leakage circuit similar to leakage circuit **108**. Each device may include a current sensor corresponding to sensor A**1**, and each current sensor may sense a different current, with the magnitude each sensed current indicating a proximity to the system power bus. For example, using the numerical example indicated in FIG. **17**A, if each PV device **107***a*, **107***b* . . . **107***k* includes a leakage circuit coupled to the "low voltage" output of a power converter **211**, and each PV device includes an identical resistor R=100 kΩ, PV device **107***a* may sense a current of approximately

$$\frac{0\text{ V}}{100\text{ k}\Omega} = 0\text{ A}.$$

PV device **107***b* may sense a current of approximately

$$\frac{25\text{ V}}{100\text{ k}\Omega} = 0.25\text{ mA}.$$

PV device **107***c* may sense a current of approximately

$$\frac{55\text{ V}}{100\text{ k}\Omega} = 0.55\text{ mA}.$$

PV device **107***j* may sense a current of approximately

$$\frac{650\text{ V}}{100\text{ k}\Omega} = 6.5\text{ mA}.$$

PV device **107***k* may sense a current of approximately

$$\frac{660.7\text{ V}}{100\text{ k}\Omega} = 6.607\text{ mA}.$$

It may be observed that the closer a PV device is to the power bus, the higher the magnitude of the sensed current may be, and in some embodiments, it may be possible to estimate the relative order of the PV devices **107***a* . . . **107***k* with regard to the power bus by comparing the current magnitude sensed by each PV device.

Reference is now made to FIG. **17***b*, which shows a leakage circuit according to an illustrative embodiment. PV device **1007** may be used instead of PV devices **107** in FIG. **17**A. For example, PV devices **107***a*-**107***k* of FIG. **17**A may be replaced by a corresponding plurality of PV devices **1007***a-k*. PV device **1007** may comprise controller **214**, power converter **211** and communication device **212**, which may be the same as controller **214**, power converter **211** and communication device **212** of FIG. **17**A. PV device **1007** may feature a leakage terminal (LT) similar to that of PV device **107**. Leakage circuit **1008** may comprise voltage sensor V**1** and resistors R**1** and R**2**. Resistor R**2** may have a very large resistance, such as 100 MΩ, 1 GΩ, 2 GΩ or even 10 GΩ. R**1** may be substantially smaller than R**2**. For example, R**1** may have a resistance of under %1 of R**2**. A high-impedance current path may be provided between leakage terminal LT and the ground, via resistors R**1** and R**2**. R**1** and R**2** may be of sufficient resistance to hold leakage current to a small value, which may reduce losses due to the leakage current. For example, R**2** may be 5 GΩ and R**1** may be 10 MΩ, for a total resistance of 5.01 GΩ. If the voltage at LT is 500V, the leakage current will be about 100 μA. Voltage sensor V**1** may measure the voltage across resistor R**1**. Since R**2** may be much larger than R**1**, R**2** may absorb the majority of the voltage drop at leakage terminal LT. As an illustrative example, assume that R**2** is 99 times as large as R**1**, resulting in R**2** absorbing 99 percent of the voltage drop at LT, and R**2** absorbing 1 percent of the voltage drop at LT. If a series of PV devices **1007** are serially coupled, each having a leakage terminal and a leakage circuit **1008**, each respective voltage sensor V**1** of each respective leakage circuit **1008** will measure a voltage equal to about %1 of the voltage at the respective leakage terminal. By determining a relative order in magnitude of the respective voltage measurements, an order of the serially-coupled PV devices **1007** may be determined (e.g. by a centralized controller which may receive the voltage measurements measured by the respective voltage sensors).

FIG. **18** is a flow diagram of a method for determining the order of power devices within a PV string, which may be similar to the PV string illustrated in FIG. **17**A. At step **170**, some power devices may be considered "unsampled," i.e. power devices at which leakage currents have not been sampled. At step **171**, a power device from a group of unsampled devices may be selected. In some embodiments, a device may be selected from a group of unsampled devices at random. In some embodiments, a device may be selected from a group of unsampled devices according to predetermined criteria, such as according to an estimated location within a PV string. At step **172**, a power device selected at step **171** is commanded to activate the power device's leakage circuit. A power device command may be received via various communication methods, for example PLC and/or wireless communications, and the command may be sent by a system management unit. At step **173**, upon reception of a command to activate a leakage circuit, a power device's leakage circuit may be activated. A leakage circuit may be similar to the one illustrated in FIG. **17**A, and an activation of a leakage circuit may comprise setting the switch Q to the ON position. A current sensor similar to the sensor A**1** illustrated in FIG. **17**A may measure a leakage current obtained when Q is at the ON position. At step **174**, a leakage current may be measured and the measurement may be saved to a data logging device. The data logging device may comprise flash memory, EEPROM or other memory devices. At step **175**, the power device selected at step **171** may be removed from the pool of unsampled devices, and a command may be issued to the power device to deactivate the power device's leakage circuit. Deactivation may comprise setting the switch Q to the OFF state. At step **176** the method may determine if additional power devices are to be sampled. In some embodiments, the method will sample the leakage current of each power device in the string, and as long as there is at least one power device which has not yet activated its leakage circuit, the method will loop back to step **170**. In some embodiments, may method may proceed to step **177** even if some power devices have not yet activated their respective leakage circuits. At step **177**, the logged leakage current measurements may be compared, and based on the measurements, a relative order of power devices corresponding to the leakage current measurements may be estimated. For example, if three leakage currents have been measured, for example I_A, I_B, I_C, with the three current measurements corresponding to power devices D_A, D_B, D_C, and if $I_A<I_B<I_C$, then the method may determine that D_C may be the closest device of the three to the power bus, and that D_A may be the farthest of the three devices from the power bus. If leakage currents of all power devices in a PV string have been sampled, it may be possible in some embodiments to determine the order of all of the power devices in the string.

Reference is now made to FIG. **19**, which illustrates a portion of a photovoltaic installation and a mapping Unmanned Aerial Vehicle (UAV) according to an illustrative embodiment. Photovoltaic (PV) installation **199** may comprise PV modules **191**. One or more Unmanned Aerial Vehicles (UAV) **190** may be used to obtain Estimated Layout Map (ELM) of PV installation **199**, i.e., to determine the relative order and/or location of PV modules **191**. PV modules **191** may comprise PV generators (e.g. one or more PV cells, PV strings, PV substrings, PV panels, PV shingles, etc.) coupled to photovoltaic power devices (e.g. PV optimizers, DC/DC converters, DC/AC inverters). In some embodiments, each PV module **191** may comprise an identification label (ID label) which may be readable by UAV **190**. The ID label may be a barcode, serial number, RFID tag, memory device or any other medium for containing information that can be read by an external device, with UAV **190** comprising an appropriate device for reading the ID label. For example, each PV module **191** may have an RFID tag, while UAV **190** may have an RFID reader. In some embodiments, each PV module **191** may have a barcode sticker, tag, while UAV **190** may have a barcode scanner. UAV **190** may have various functional devices similar to those comprising combined device **700** of FIG. **7**. For example, UAV **190** may comprise controller **195**, communication device **196**, GPS device **194**, ID reader **193**, and data logging device **192**, which may be similar to or the same as ID reader **203**, GPS device **201**, data logging device **202**, controller **205**, and communication device **206** of FIG. **7**.

In some embodiments, UAV **190** may automatically read the ID tag of each of PV modules **191**. In some embodiments, UAV **190** may be in proximity to each PV module at the time the PV module's ID tag is read, and use GPS device **194** to estimate the coordinates of the PV module being scanned. The method of FIG. **2**A may be used to generate an ELM of the PV installation using the measured or estimated GPS coordinates of the PV modules.

UAV **190** may be variously realized. For example, a drone, miniature helicopter, remote-controlled airplane or various other UAVs may be utilized.

In some embodiments, UAV **190** may comprise a thermal camera. For example, camera **197** may be a thermal camera for obtaining a thermal image of PV installation **199**, and by taking multiple thermal images of PV installation **199** over time, relative locations of PV modules may be estimated for generating an ELM, using methods disclosed herein.

Reference is now made to FIG. **20**, which illustrates thermal properties of photovoltaic generators (e.g. photovoltaic panels) which may be featured in accordance with methods and apparatuses disclosed herein. Some types of photovoltaic panels may generate increased heat when photovoltaic power generated by the panel is not provided to an electrical load. Photovoltaic power may be generated by a PV panel as a result of photovoltaic cells mounted on the PV panel absorbing solar irradiance. When an electrical load is coupled to a PV panel, some of the absorbed solar irradiance may be converted to electrical power provided to the load. If no electrical load (or a reduced electrical load) is coupled to the PV panel, an increased portion of the absorbed irradiance may be converted to heat, which may result in an increased temperature of the PV panel. If an electrical load is coupled to a PV panel, but the load only draws a small portion of the PV power produced by the panel, the panel temperature may be lower than the temperature when compared to the "no-load" case, but may be higher than the temperature that would be measured if an electrical load drew an increased amount of PV power from the PV panel.

FIG. **20** illustrates an illustrative thermal image of a group of PV generators (which may be used as PV modules **191** of FIG. **19**). PV generators **2001***b* may be providing a first level of electrical power (e.g. 300 watts) to a load, PV generators **2001***c* may be providing a second level of electrical power (e.g. 200 watts) to an electrical load, and PV generators **2001** may be providing a third, lower level of electrical power (e.g. 50 W) to an electrical load, or might not be providing any electrical power to a load. All of PV generators **2001***a*-**2001***c* may be irradiated by substantially the same level of solar irradiance. As indicated by temperature bar **2002**, a reduced provision of electrical power to a load may increase a temperature of an associated PV generator in a manner (e.g. by about 4° C.) which may be visually detectable by a thermal image.

Reference is now made to FIG. **20**, which illustrates a thermal image portion of a photovoltaic string according to an illustrative embodiment. PV panels **2001***a*-**2001***f* may be coupled in series or in parallel to form part of a PV string. At the time the thermal image was obtained, PV panels **2001***a*-**2001***e* were coupled to an electrical load, and PV panel **2001***f* was not coupled to an electrical load. PV panel **2001***f* may be observed to be visually distinguishable compared to PV panels **2001***a*-**2001***e*.

Referring back to FIG. **19**, camera **197** may be used to obtain thermal images similar to the thermal images illustrated in FIGS. **20**A-**20**C, with controller **195** configured to implement a method for determining a ELM from images obtained by camera **197**. A succession of thermal images similar to the images of FIGS. **20**A-**20**C may be obtained and stored in data logging device **192**, with controller **195** configured to read the images from data logging device **192** for processing.

Reference is now made to FIG. **21**, which illustrates a method for installation mapping according to one or more illustrative aspects of the disclosure. Method **2100** may be carried out by a controller comprised by a UAV (e.g. controller **195** of FIG. **19**), or by a system-level controller in communication with PV modules and/or a UAV, or by a combination thereof. For illustrative purposes, it will be assumed that method **2100** is carried out by controller **195** of FIG. **19** and applied to PV modules **191** of FIG. **19**. Each PV module **191** may comprise a PV power device capable of increasing or decreasing the electrical power drawn from the PV model. For example, in some embodiments, each PV module **191** may comprise a disconnect switch configured to disconnect the PV module from a string of PV modules which coupled to an electrical load. By disconnecting a selected PV module from the string of PV modules, the selected PV module may cease providing power to the electrical load, and the temperature of the selected PV module may rise. In some embodiments, each PV module **191** may be coupled to an optimizer, each optimizer configured to increase or reduce the power drawn from the corresponding PV module.

PV power devices coupled to PV modules **191** may be in communication with a controller carrying out method **2100** or part thereof. For example, PV power devices coupled to PV modules **191** may comprise wireless communication devices configured to communicate with communication device **196** of UAV **190**.

Method **2100** may be applied to a group of PV modules without regard for interconnectivity. Method **2100** may effectively map PV modules which are electrically connected (e.g. modules which are part of the same PV string) and may effectively map PV modules which are not electrically connected (e.g. modules which are part of different PV strings).

At the start of method **2100**, at step **1220**, all PV modules in the group are considered "untested". At step **1221**, a controller (i.e. the controller carrying out method **2100** or part of method **2100**) may select a PV module from the pool of untested PV modules. At step **1222**, the controller reduces the electrical power drawn from the selected PV module. For example, the controller may command a PV power device (e.g. a disconnect switch or an optimizer) coupled to the PV module to reduce the electrical power drawn from the PV module (e.g. by disconnected the PV module from a load, or by operating the PV module at an operating point which reduces the power drawn from the PV module.

After the electrical power drawn from the PV module is reduced, it may take several minutes for the temperature of the PV module to substantially rise. The controller may wait for a period of time (e.g. 3, 5, 10 or 20 minutes) before proceeding to step **1223**.

At step **1223**, the controller may control a thermal imaging device (e.g. camera **197**) to obtain a thermal image of the group of PV modules. At step **1224**, the controller may analyze the thermal image to find "hot spots", e.g., areas in the image which indicate a higher temperature. In some embodiments, the thermal image may comprise temperature measurements which may be numerically compared. In some embodiments, the thermal image may be represented by pixels of varying colors and/or shades of gray, with the controller configured to process the image and detect areas comprising pixels which may be indicative of a higher temperature (e.g. red, or darker shades of gray).

At step **1225**, the controller may estimate the relative location of a hot spot detected at step **1224**. For example, the controller may determine that the group of PV modules comprises nine PV modules placed side-by-side (e.g. similar to the depiction of FIG. **20**C), with the fourth PV module from the right (i.e. PV module **2001**) hotter than the rest. In some embodiments, the controller may have estimated physical coordinates of one of the PV modules, and may use the estimated coordinates as an "anchor" node for estimating locations of the other PV modules. In some embodiments, the controller may determine a relative ordering or relational placements (e.g. to the right of, to the left of, in front of, behind) of the PV modules in the group, and aggregate the relational placements to generate a ELM.

In an embodiment, method **2100** may be adapted to have all PV devices initially not providing substantial power to an electrical load. The method may be adapted at step **1222** to increase the electrical power drawn from the selected PV module, at steps **1224**-**1225** to detect and estimate "cold spot" locations, and at step **1226** to decrease the electrical power drawn from the selected PV module.

At step **1226**, the PV module selected at step **1221** is removed from the group of untested PV modules, and the power drawn from the selected PV module is increased (e.g. by commanding a disconnect switch to reconnect the PV module to an electrical load, or commanding an optimizer to operate the PV module at an increased-power operating point).

At step **1227**, the controller determines if untested PV modules remain, i.e., if there are PV modules in the group which have not yet been selected at step **1221**. If untested PV modules remain, the controller may loop back to step **1221**. If no untested PV modules remain, the controller may proceed to step **1228**.

At step **1228**, the controller may aggregate the hot spot locations estimated at step **1225** over the method iterations, to produce an estimated ELM.

In an alternative embodiment, thermal images obtained at step **1223** may be saved to memory, with steps **1224**-**1225** carried out after the final iteration of step **1227**. In other words, analysis of thermal images may be delayed until after a full set of thermal images (one per iteration through steps **1221**-**1227**) has been obtained. In a preferred embodiment, steps **1224**-**1225** are carried out in the order indicated in FIG. **21**, to enable the controller to repeat iterations if needed. For example, method **2100** may comprise an additional step of ensuring that a "hot spot" has been detected at step **1224**, and in the event that the method has not identified a hot spot in the thermal image obtained at step **1223**, having the method loop back to step **1221**, or alternatively, wait an additional several minutes and then loop back to step **1223**.

Method **2100** may be combined with other methods disclosed herein, for example, to increase the accuracy of ELMs and PIMs generated by methods disclosed herein. For example, method **2100** may be used to obtain an initial ELM, with the method of FIG. **18** used for validation (or vice-versa).

In some embodiments, reference was made to "upper" and "lower" junction box portions. This language was used for ease and is not intended to be limiting. In some embodiments, the two portions may be side-by-side, and/or functional circuitry may be transferred from one junction box portion to other, in a manner that allows them to be in electrical communication when coupled to one another.

In the illustrative embodiments disclosed herein, PV modules are used to exemplify energy sources which may make use of the novel features disclosed. In some embodiments, the energy sources may include batteries, wind or hydroelectric turbines, fuel cells or other energy sources in addition to or instead of PV modules. The current routing methods and other techniques disclosed herein may be applied to alternative energy sources such as those listed above, and the mentioning of PV modules as energy sources is for illustrative purposes only and not intended to be limiting in this respect. For example, any other energy sources or combination of energy sources may be used.

It is noted that various connections are set forth between elements herein. These connections are described in general and, unless specified otherwise, may be direct or indirect; this specification is not intended to be limiting in this respect. Further, elements of one embodiment may be combined with elements from other embodiments in appropriate combinations or subcombinations.

What is claimed is:

1. An apparatus comprising:

a power electronics device comprising output terminals configured to output electrical power at an electrical current value;

a communication circuit configured to receive a command to change a voltage or an impedance of the output terminals, wherein the command comprises information identifying the power electronics device; and

a controller configured to, based on the command, change the voltage or the impedance of the output terminals independent of the electrical current value.

2. The apparatus of claim **1**, wherein the power electronics device comprises at least one element from the group consisting of a direct current (DC) to DC converter, a DC to alternating current (AC) converter, a photovoltaic module, a junction box, a Maximum Power Point Tracking (MPPT) circuit, a sensor circuit, a fuse, a variable impedance circuit, a switch, and a circuit breaker.

3. The apparatus of claim **1**, wherein the communication circuit comprises a wireless interface or a power line communication interface.

4. The apparatus of claim **3**, wherein the communication circuit comprises the wireless interface, and wherein the controller is configured to retrieve, from the wireless interface, at least one measured or estimated value from the group consisting of a Received Signal Strength Indication (RSSI), an Angle or Direction of Arrival, and Time Difference of Arrival (TDOA).

5. The apparatus of claim **3**, wherein the communication circuit comprises the power line communication interface, and wherein the controller is configured to use time domain reflectometry via the power line communication interface to determine an order of other apparatuses serially connected to the output terminals.

6. The apparatus of claim **1**, wherein the power electronics device comprises input terminals, and wherein the controller is further configured to control an operational parameter of one or more photovoltaic (PV) modules coupled to the input terminals of the power electronics device, wherein the operational parameter is a parameter from the group consisting of a voltage, a current, a temperature, and an impedance.

7. The apparatus of claim **1**, wherein the information identifying the power electronics device distinguishes the power electronics device from one or more other power electronics devices.

8. A method comprising:

receiving a command, using a communication circuit of a power electronics device comprising output terminals, to change a voltage or an impedance of the output terminals, wherein the power electronics device is configured to output electrical power using the output terminals at an electrical current value, and wherein the command comprises information identifying the power electronics device;

comparing, by a controller of the power electronics device, the identifying information of the received command with the identifying information of the power electronics device; and

when a match exists, changing the voltage or the impedance of the output terminals to comply with the command independent of the electrical current value.

9. The method of claim **8**, wherein the power electronics device comprises at least one element from the group consisting of a direct current (DC) to DC converter, a DC to alternating current (AC) converter, a photovoltaic module, a junction box, a Maximum Power Point Tracking (MPPT) circuit, a sensor circuit, a fuse, a variable impedance circuit, and a circuit breaker.

10. The method of claim **8**, wherein the communication circuit comprises a wireless interface or a power line communication interface.

11. The method of claim **10**, wherein the communication circuit comprises the wireless interface, and wherein the controller is configured to retrieve, from the wireless interface, at least one measured or estimated value from the group consisting of a Received Signal Strength Indication (RSSI), an Angle or Direction of Arrival, and Time Difference of Arrival (TDOA).

12. The method of claim **10**, wherein the communication circuit comprises the power line communication interface, and wherein the controller is configured to use time domain reflectometry via the power line communication interface to determine an order of other apparatuses serially connected to the output terminals.

13. An apparatus, comprising:

a communication circuit configured to transmit and receive information; and

a controller configured to:

send a command, using the communication circuit, to a first power device comprising output terminals to change a voltage or an impedance of the output terminals independent of an electrical current value;

receive, using the communication circuit, output parameters reported by a plurality of power devices; and determine, by analyzing the output parameters and the command, which power devices of the plurality of power devices are serially coupled to the first power device.

14. The apparatus of claim **13**, further comprising at least one element from the group consisting of a DC to DC converter, a DC to AC converter, a photovoltaic module, a junction box, a MPPT circuit, a sensor circuit, a fuse, a variable impedance circuit, a switch, and a circuit breaker.

15. The apparatus of claim **13**, further comprising a DC to AC converter configured to receive solar energy from the plurality of power devices, convert the solar energy by modifying at least one electrical parameter of the solar energy, and send the converted solar energy to an electrical network.

16. The apparatus of claim **13**, wherein the communication circuit comprises a wireless interface or a power line communication interface.

17. The apparatus of claim **16**, wherein the communication circuit comprises the wireless interface, and wherein the controller is configured to retrieve, from the wireless interface, at least one measured or estimated value from the group consisting of a Received Signal Strength Indication (RSSI), an Angle or Direction of Arrival, and Time Difference of Arrival (TDOA).

18. The apparatus of claim **16**, wherein the communication circuit comprises the power line communication interface, and wherein the controller is configured to use time domain reflectometry via the power line communication interface to determine an order of other apparatuses serially connected to the output terminals.

19. The apparatus of claim **16**, wherein the controller and the communication circuit are incorporated into a computer system.

20. A system comprising:

a plurality of power sources;

a plurality of power devices, each power device coupled to a respective at least one power source of the plurality of power sources, wherein at least some of the plurality of power devices are connected to form a serial string; and

a system power device configured to send a command, via a communication device, to a selected power device of the plurality of power devices to change a voltage or an impedance of output terminals of the selected power device independent of electrical current between the output terminals;

and wherein the system power device comprises:

the communication device; and

a controller configured to:

send the command to the selected power device wherein the command comprises information identifying the selected power device;

receive electrical parameters from the plurality of power devices; and

analyze the electrical parameters and the command to determine which of the plurality of power devices are serially connected to the selected power device.

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